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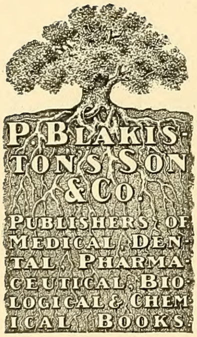
A

TEXT-BOOK OF HUMAN PHYSIOLOGY.

BRUBAKER.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PUBLISHERS OF MEDICAL DENTAL PHARMACEUTICAL, BIOLOGICAL & CHEMICAL BOOKS

A

TEXT-BOOK

OF

HUMAN PHYSIOLOGY.

INCLUDING A SECTION ON

PHYSIOLOGIC APPARATUS.

BY

ALBERT P. BRUBAKER, A.M., M.D.,

PROFESSOR OF PHYSIOLOGY AND HYGIENE IN THE JEFFERSON MEDICAL COLLEGE; PROFESSOR
OF PHYSIOLOGY IN THE PENNSYLVANIA COLLEGE OF DENTAL SURGERY;
LECTURER ON PHYSIOLOGY AND HYGIENE IN THE DREXEL
INSTITUTE OF ART, SCIENCE, AND INDUSTRY.

THIRD EDITION. REVISED AND ENLARGED.
WITH COLORED PLATES AND 383 ILLUSTRATIONS.

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TO

HENRY C. CHAPMAN, M.D.,

PROFESSOR OF INSTITUTES OF MEDICINE AND MEDICAL JURISPRUDENCE IN
THE JEFFERSON MEDICAL COLLEGE.

IN GRATEFUL RECOGNITION OF THE MANY KINDNESSES RECEIVED FROM
HIM, DURING A PERIOD OF TWENTY-FIVE YEARS, THIS
VOLUME IS RESPECTFULLY DEDICATED BY

THE AUTHOR.

PREFACE TO THIRD EDITION.

THE publishers having requested the preparation of a Third Edition of the TEXT-BOOK OF PHYSIOLOGY, an attempt has been made to still further increase its value to those for whom it was primarily intended by subjecting the whole text to a careful revision, by the insertion of a number of new diagrams and by the incorporation of new material. In this attempt the author has been assisted by the suggestions contained in reviews and in letters received from teachers and students. Altogether some fifty additional pages have been added to the body of the text. This material will be found in the chapters on the chemistry of the proteids, the physiology of muscle tissue, absorption, the physiology of the heart and vascular apparatus, the nerve system and vision.

Once again I wish to express my sincere thanks to those teachers and students who have used and recommended this book and for the generous praise they have bestowed on it verbally and by letter and trust that in its present form it will still further meet their approval.

I am indebted to Dr. George Bachmann for the new diagrams in the text to which his name is appended.

To Mr. I. A. Hagy my thanks are due for invaluable assistance in seeing the work through the press.

To Messrs. P. Blakiston's Son & Co. I am greatly indebted for their encouragement and generosity in the promotion of every thing that pertains to the material value of this work.

A. P. B.

PREFACE.

THE object in view in the preparation of this volume was the selection and presentation of the more important facts of physiology, in a form which it is believed will be helpful to students and to practitioners of medicine. Inasmuch as the majority of students in a medical college are preparing for the practical duties of professional life, such facts have been selected as will not only elucidate the normal functions of the tissues and organs of the body, but which will be of assistance in understanding their abnormal manifestations as they present themselves in hospital and private work. Both in the selection of facts and in the method of presentation the author has been guided by an experience gained during twenty years of active teaching.

The description of physiologic apparatus and the methods of investigation, other than those having a clinical interest, have been largely excluded from the text, for the reason that both are more appropriately considered in works devoted to laboratory methods and laboratory instruction, and for the further reason that the student receives this information while engaged in the practical study of physiology in the laboratory, now an established feature in the curriculum of the majority of medical colleges. For those who have not had laboratory opportunities a brief account of some essential forms of apparatus and the purposes for which they are intended will be found in an appendix.

I wish to acknowledge my indebtedness to Professor Colin C. Stewart for many valuable suggestions in the preparation of different sections of the volume; to Dr. Carl Weiland for assistance in the chapter on vision; to Dr. Joseph P. Bolton for excellent suggestions on questions relating to physiologic chemistry.

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TEXT-BOOK OF PHYSIOLOGY.

CHAPTER I.

INTRODUCTION.

An animal organism in the living condition exhibits a series of phenomena which relate to growth, movement, mentality, and reproduction. During the period preceding birth, as well as during the period included between birth and adult life, the individual grows in size and complexity from the introduction and assimilation of material from without. Throughout its life the animal exhibits a series of movements, in virtue of which it not only changes the relation of one part of its body to another, but also changes its position relatively to its environment. If, in the execution of these movements, the parts are directed to the overcoming of opposing forces, such as gravity, friction, cohesion, elasticity, etc., the animal may be said to be doing work. The result of normal growth is the attainment of a physical development that will enable the animal, and, more especially, man, to perform the work necessitated by the nature of its environment and the character of its organization. In man, and probably in lower animals as well, mentality manifests itself as intellect, feeling, and volition. At a definite period in the life of the animal it reproduces itself, in consequence of which the species to which it belongs is perpetuated.

The study of the phenomena of growth, movement, mentality, and reproduction constitutes the science of **animal physiology.** But as these general activities are the resultant of and dependent on the special activities of the individual structures of which an animal body is composed, **physiology** in its more restricted and generally accepted sense is the science which investigates the actions or functions of the individual organs and tissues of the body and the physical and chemic conditions which underlie and determine them.

This may naturally be divided into:

1. *Special physiology*, the object of which is a study of the vital phenomena or functions exhibited by the organs of any individual animal.

2. *Comparative physiology*, the object of which is a comparison of the vital phenomena or functions exhibited by the organs of two or more animals of different species, with a view to unfolding their points of resemblance or dissimilarity.

Human physiology is that department of physiologic science which has for its object the study of the functions of the organs of the human body in a state of health.

Inasmuch as the study of function, or physiology, is associated with and dependent on a knowledge of structure, or anatomy, it is essential that the student should have a general acquaintance not only with the structure of man, but with that of typical forms of lower animal life as well.

If the body of any animal be dissected, it will be found to be composed of a number of well-defined structures, such as heart, lungs, stomach, brain, eye, etc., to which the term organ was originally applied, for the reason that they were supposed to be instruments capable of performing some important act or function in the general activities of the body. Though the term organ is usually employed to designate the larger and more familiar structures just mentioned, it is equally applicable to a large number of other structures which, though possibly less obvious, are equally important in maintaining the life of the individual—*e. g.*, bones, muscles, nerves, skin, teeth, glands, blood-vessels, etc. Indeed, any complexly organized structure capable of performing a given function may be described as an organ. A description of the various organs which make up the body of an animal, their external form, their internal arrangement, their relations to one another, constitutes the science of **animal anatomy.**

This may naturally be divided into:

1. *Special anatomy*, the object of which is the investigation of the construction, form, and arrangement of the organs of any individual animal.
2. *Comparative anatomy*, the object of which is a comparison of the organs of two or more animals of different species, with a view to determining their points of resemblance or dissimilarity.

If the organs, however, are subjected to a further analysis, they can be resolved into simple structures, apparently homogeneous, to which the name tissue has been given—*e. g.*, epithelial, connective, muscle, and nerve tissue. When the tissues are subjected to a microscopic analysis, it is found that they are not homogeneous in structure, but composed of still simpler elements, termed cells and fibers. The investigation of the internal structure of the organs, the physical properties and structure of the tissues, as well as the structure of their component elements, the cells and fibers, constitutes a department of anatomic science known as **histology,** or as it is prosecuted largely with the microscope, **microscopic anatomy.**

Human anatomy is that department of anatomic science which has for its object the investigation of the construction of the human body.

GENERAL STRUCTURE OF THE ANIMAL BODY.

The body of every animal, from fish to man, may be divided into—

1. An axial portion, consisting of the head, neck, and trunk; and—
2. An appendicular portion, consisting of the anterior and posterior limbs or extremities.

The **axial portion** of all mammals, to which class man zoölogically belongs, as well as of all birds, reptiles, amphibians, and osseous fish, is characterized by the presence of a bony, segmented axis, which extends in a longitudinal direction from before backward, and which is known as the vertebral column or backbone. In virtue of the existence of this column all the classes of animals just mentioned form one great division of the animal kingdom, *the Vertebrata.*

Each segment, or vertebra, of this axis consists of—

1. A solid portion, known as the body or centrum, and
2. A bony arch arising from the dorsal aspect and surmounted by a spine-like process.

At the anterior extremity of the body of the animal the vertebræ are variously modified and expanded, and, with the addition of new elements, form the skull; at the posterior extremity they rapidly diminish in size, and terminate in man in a short, tail-like process. In many animals, however, the vertebral column extends for a considerable distance beyond the trunk into the tail. The vertebral column may be regarded as the foundation element in the plan of organization of all the higher animals and the center around which the rest of the body is developed and arranged with a certain degree of conformity. In all vertebrate animals the bodies of the segments of the vertebral column form a partition which serves to divide the trunk of the body into two cavities—viz., the dorsal and the ventral. (See Fig. 1.)

The **dorsal cavity** is found not only in the trunk, but also in the head. Its walls are formed partly by the arches which arise from the posterior or dorsal surface of the vertebræ and partly by the bones of the skull. If a longitudinal section be made through the center of the vertebral column, and including the head, the dorsal cavity will be observed running through its entire extent. Though for the most part it is quite narrow, at the anterior extremity it is enlarged and forms the cavity of the skull. This cavity is lined by a membranous canal, the neural canal, in which are contained the brain and the neural or spinal cord. Through openings in the sides of the dorsal cavity nerves pass out which connect the brain and spinal cord with all the structures of the body.

The **ventral cavity** is confined mainly to the trunk of the body. Its walls are formed by muscles and skin, strengthened in most animals by bony arches, the ribs. Within the ventral cavity is contained a musculo-membranous tube or canal known as the alimentary or food canal, which begins at the mouth on the ventral side of the head, and, after passing through the neck and trunk, terminates at the posterior extremity of the trunk at the anus. It may be divided into mouth, pharynx, esophagus, stomach, small and large intestines.

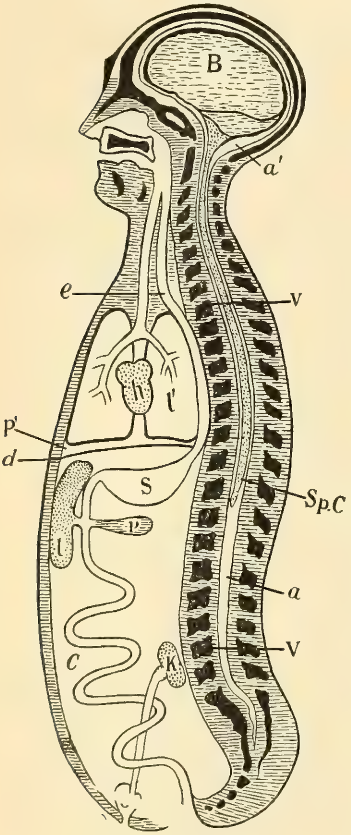

Fig. 1.—Diagrammatic Longitudinal Section of the Body. V, V. Bodies of the vertebræ which divide the body into the dorsal and ventral cavities. *a*, *a'*. The dorsal cavity. C, *p'*. The abdominal and thoracic divisions of the ventral cavity, separated from each other by a transverse muscular partition, the diaphragm *d*. B. The brain. Sp.C. The spinal cord. *e*. The esophagus. S. The stomach, from which continues the intestine to the opening at the posterior portion of the body. *l*. The liver. *p'*. The pancreas. *k*. The kidney. *o*. The bladder. *l'*. The lungs. *h*. The heart.

In all mammals the ventral cavity is divided by a musculo-membranous partition into two smaller cavities, the thorax and abdomen. The former contains the lungs, heart and its great blood-vessels, and the anterior part of the alimentary canal, the gullet or esophagus; the latter contains the continuation of the alimentary canal—that is, the stomach and intestines—and the glands in connection with it, the liver and pancreas. In the posterior portion of the abdominal cavity are found the kidneys, ureters, and bladder, and in the female the organs of reproduction. The thoracic and abdominal cavities are each lined by a thin serous membrane, known, respectively, as the pleural and peritoneal membranes, which, in addition, are reflected over the surfaces of the organs contained within them. The alimentary canal and the various cavities connected with it are lined throughout by a mucous membrane.

The surface of the body is covered by the skin. This is composed of an inner portion, the derma, and an outer portion, the epidermis. The former consists of fibers, blood-vessels, nerves, etc.; the latter of layers of scales or cells. Embedded within the skin are numbers of glands; which exude, in the different classes of animals, sweat, oily matter, etc. Projecting from the surface of the skin are hairs, bristles, feathers, claws. Beneath the skin are found muscles, bones, blood-vessels, nerves, etc.

The **appendicular portion** of the body consists of two pairs of symmetric limbs, which project from the sides of the trunk, and which bear a determinate relation to the vertebral column. They consist fundamentally of bones, surrounded by muscles, blood-vessels, nerves and lymphatics. The limbs, though having a common plan of organization, are modified in form and adapted for prehension and locomotion in accordance with the needs of the animal.

Anatomic Systems.—All the organs of the body which have certain peculiarities of structure in common are classified by anatomists into systems—*e. g.*, the bones, collectively, constitute the bony or osseous system; the muscles, the nerves, the skin, constitute, respectively, the muscle, the nerve, and the tegumentary systems.

Physiologic Apparatus.—More important from a physiologic point of view than a classification of organs based on similarities of structure is the natural association of two or more organs acting together for the accomplishment of some definite object, and to which the term physiologic apparatus has been applied. While in the community of organs which together constitute the animal body each one performs some definite function, and the harmonious coöperation of all is necessary to the life of the individual, everywhere it is found that two or more organs, though performing totally distinct functions, are coöperating for the accomplishment of some larger or compound function in which their individual functions are blended—*e. g.*, the mouth, stomach, and intestines, with the glands connected with them, constitute the *digestive apparatus*, the object or function of which is the complete digestion of the food. The capillary blood-vessels and lymphatic vessels of the body, and especially those in relation to the villi of the small intestine, constitute the *absorptive apparatus*, the function of which is the introduction of new material into the blood. The heart and blood-vessels constitute the *circulatory apparatus*, the function of which is the distribution of blood to all portions of the body. The lungs and trachea, together with the diaphragm and the walls of the chest, constitute the *respiratory apparatus*, the function of which is the introduction of oxygen into the blood and the elimination from it of carbon dioxid and other injurious products. The kidneys, the ureters, and the bladder constitute the *urinary apparatus*. The skin, with its sweat-glands, constitutes the *perspiratory apparatus*, the functions of both being the excretion of waste products from the body. The liver, the pancreas, the mammary glands, as well as other glands, each form a *secretory apparatus* which elaborates some specific material necessary to the nutrition of the individual. The functions of these different physiologic apparatus—*e. g.*, digestion, absorption of food, elaboration of blood, circulation of blood, respiration, production of heat, secretion, and excretion—are classified as *nutritive functions*, and have for their final object the preservation of the individual.

The nerves and muscles constitute the *nervo-muscle apparatus*, the function of which is the production of motion. The eye, the ear, the nose, the tongue, and the skin, with their related structures, constitute, respectively, the *visual*, *auditory*, *olfactory*, *gustatory*, and *tactile apparatus*, the function of which, as a whole, is the reception of impressions and the transmission of nerve impulses to the brain, where they give rise to visual, auditory, olfactory, gustatory, and tactile sensations and volitional impulses.

The brain, in association with the sense organs, forms an apparatus related to mental processes. The larynx and its accessory organs—the lungs, trachea, respiratory muscles, the mouth and resonant cavities of the face—form the *vocal* and *articulating apparatus*, by means of which voice and articulate speech are produced. The functions exhibited by the apparatus just mentioned—viz., motion, sensation, language, mental and moral manifestations—are classified as *functions of relation*, as they serve to bring the individual into conscious relationship with the external world.

The ovaries and the testes are the essential reproductive organs, the former producing the germ-cell, the latter the sperm element. Together with their related structures—the fallopian tubes, uterus, and vagina in the female, and the urogenital canal in the male—they constitute the *reproductive apparatus* characteristic of the two sexes. Their coöperation results in the union of the germ-cell and sperm element and the consequent development of a new being. The function of reproduction serves to perpetuate the species to which the individual belongs.

The animal body is therefore not a homogeneous organism, but one composed of a large number of widely dissimilar but related organs. As all vertebrate animals have the same general plan of organization, there is a marked similarity both in form and structure among corresponding parts of different animals. Hence it is that in the study of human anatomy a knowledge of the form, construction, and arrangement of the organs in different types of animal life is essential to its correct interpretation; it follows also that in the investigation and comprehension of the complex problems of human physiology a knowledge of the functions of the organs as they manifest themselves in the different types of animal life is indispensable. As many of the functions of the human body are not only complex, but the organs exhibiting them are practically inaccessible to investigation, we must supplement our knowledge and judge of their functions by analogy, by attributing to them, within certain limits, the functions revealed by experimentation upon the corresponding organs of lower animals. This experimental knowledge, corrected by a study of the clinical phenomena of disease and the results of post-mortem investigations, forms the basis of modern human physiology.

CHAPTER II.

CHEMIC COMPOSITION OF THE HUMAN BODY.

Since it has been demonstrated that every exhibition of functional activity is associated with changes of structure, it has been apparent that a knowledge of the chemic composition of the body, not only when in a state of rest, but to a far greater degree when in a state of activity, is necessary to a correct understanding of the intimate nature of physiologic processes. Though the analysis of the dead body is comparatively easy, the determination of the successive changes in composition of the living body is attended with many difficulties. The living material, the bioplasm, is not only complex and unstable in composition, but extremely sensitive to all physical and chemic influences. The methods, therefore, which are employed for analysis destroy its composition and vitality, and the products which are obtained are peculiar to dead rather than to living material.

Chemic analysis, therefore, may be directed—

1. To the determination of the composition of the dead body.
2. To the determination of the successive changes in composition which the living bioplasm undergoes during functional activity.

A chemic analysis of the dead body, with a view to disclosing the substances of which it is composed, their properties, their intimate structure, their relationship to one another, constitutes what might be termed **chemic anatomy.** An investigation of the living material and of the successive changes it undergoes in the performance of its functions constitutes what has been termed **chemic physiology** or **physiologic chemistry.**

By chemic analysis the animal body can be reduced to a number of liquid and solid compounds which belong to both the inorganic and organic worlds. These compounds, resulting from a proximate analysis, have been termed proximate principles. That they may merit this term, however, they must be obtained in the form under which they exist in the living condition. The organic compounds consist of representatives of the carbohydrate, fatty, and protein groups of organic bodies; the inorganic compounds consist of water, various acids, and inorganic salts.

The compounds or proximate principles thus obtained can be further resolved by an ultimate analysis into a small number of chemic elements which are identical with elements found in many other organic as well as inorganic compounds. The different chemic elements which are thus obtained, and the percentages in which they exist in the body, are as follows—viz., oxygen, 72 per cent.; hydrogen, 9.10; nitrogen, 2.5; carbon, 13.50; phosphorus, 1.15; calcium, 1.30; sulphur, 0.147; sodium, 0.10; potassium, 0.026; chlorin, 0.085; fluorin, iron, silicon, magnesium, in small and variable amounts.

THE CARBOHYDRATES.

The carbohydrate compounds, which enter into the composition of the animal body, are mainly starches and sugar. In many respects they are closely related, and by appropriate means are readily converted into one another. In composition they consist of the elements carbon, hydrogen, and oxygen. As their name implies, the hydrogen and oxygen are present in these compounds in the proportion in which they exist in water, or as 2 : 1. The molecule of the carbohydrates above mentioned consists of either *six* atoms of carbon or a multiple of six; in the latter case the quantity of hydrogen and oxygen taken up by the carbon is increased, though the ratio remains unchanged.

The carbohydrates may be divided into three groups—viz.: (1) *amyloses*, including starch, dextrin, glycogen, and cellulose; (2) *dextroses*, including dextrose, levulose, galactose; (3) *saccharoses*, including saccharose, lactose, and maltose. According to the number of carbon atoms entering into the second group (six), they are frequently termed monosaccharids; those of the third group, disaccharids—twice six; those of the first group, polysaccharids—multiples of six.

Though but few of the members of the carbohydrate group are constituents of the human body, many are constituents of the foods; on account of their importance in this respect, and their relation to one another, the chemic features of the more generally consumed carbohydrates will be stated in this connection.

1. AMYLOSES, $(C_6H_{10}O_5)_n$.

Starch is widely distributed in the vegetable world, being abundant in the seeds of the cereals, leguminous plants, and in the tubers and roots of many vegetables. It occurs in the form of microscopic granules which vary in size, shape, and appearance, according to the plant from which they are obtained. Each granule presents a nucleus, or hilum, around which is arranged a series of eccentric rings, alternately light and dark. The granule consists of an envelope and stroma of cellulose, containing in its meshes the true starch material—*granulose*. Starch is insoluble in cold water and alcohol. When heated with water up to 70° C., the granules swell, rupture, and liberate the granulose, which forms an apparent solution; if present in sufficient quantity, it forms a gelatinous mass termed starch paste. On the addition of iodin, starch strikes a characteristic deep blue color; the compound formed—iodid of starch—is weak, the color disappearing on heating, but reappearing on cooling.

Boiling starch with dilute sulphuric acid (twenty-five per cent.) converts it into dextrose. In the presence of vegetable diastase or animal ferments, starch is converted into maltose and dextrose, two forms of sugar.

Dextrin is a substance formed as an intermediate product in the transformation of starch into sugar. There are at least two principal varieties—*erythrodextrin*, which strikes a red color with iodin, and *achroödextrin*, which is without color when treated with this reagent. In the pure state dextrin is a yellow-white powder, soluble in water. In the presence of vegetable ferments erythrodextrin is converted into maltose.

Glycogen is a constituent of the animal liver, and, to a slight extent, of muscles and of tissues generally. In the tissues of the embryo it is especially abundant. When obtained in a pure state it is an amorphous, white powder. It is soluble in water, forming an opalescent solution. With iodin it strikes a port-wine color. In some respects it resembles starch, in others dextrin. Like vegetable starch, glycogen or animal starch can be converted by dilute acids and ferments into sugar (dextrose).

Cellulose is the basic material of the more or less solid framework of plants. It is soluble in ammoniacal solution of cupric oxid, from which it can be precipitated by acids. It is an amorphous powder; dilute acids can convert it into dextrose.

2. DEXTROSES, $C_6H_{12}O_6$.

Dextrose, glucose, or **grape-sugar** is found in grapes, most sweet fruits, and honey, and as a normal constituent of liver, blood, muscles, and other animal tissues. In the disease diabetes mellitus it is found also in the urine.

When obtained from any source, it is soluble in water and in hot alcohol, from which it crystallizes in six-sided tables or prisms. As usually met with, it is in the form of irregular, warty masses. It is sweet to the taste. When examined with the polariscope, dextrose turns the plane of polarized light to the right. It is therefore termed dextro-rotatory. It has for a long time been known that when sugar, cupric hydroxid, and an alkali—*e. g.*, sodium or potassium—are present in solution, the sugar will abstract from the cupric hydroxid a portion of its oxygen, thus reducing it to a lower stage of oxidation giving rise to cuprous oxid. Sugar has a similar action on both silver and bismuth. On this property of sugar a standard solution of cupric hydroxid was suggested by Fehling which may be employed for both qualitative and quantitative tests for the presence of sugar in solution.

Fehling's Test Solution.—This is a solution of cupric hydroxid made alkaline by an excess of sodium or potassium hydroxid with the addition of sodium and potassium tartrate. It is made by dissolving cupric sulphate 34.64 grams, potassium hydroxid 125 grams, sodium and potassium tartrate 173 grams, in distilled water sufficient to make one liter.

The reaction is expressed by the following equation:

$$CuSO_4 + 2KOH = Cu(OH)_2 + K_2SO_4.$$

The object of the sodium and potassium tartrate is to dissolve the cupric hydroxid and hold it in solution.

For qualitative analysis it is only necessary to boil a few cubic centimeters of this solution in a test-tube; then add the suspected solution and again heat to the boiling-point. If sugar be present, the cupric hydroxid is reduced to the condition of a cuprous oxid, which shows itself as a red or orange-yellow precipitate. The color of the precipitate depends on the relative excess of either copper or sugar, being red with the former, orange or yellow with the latter. The delicacy of this test is shown by the fact that a few minims of this solution will detect in 1 c.c. of water the $\frac{1}{15}$ of a milligram of sugar.

For quantitative analysis, 10 c.c. of Fehling's solution, diluted with 40 c.c. of water, are heated in a porcelain capsule, to which the suspected solution is cautiously added from a buret until the blue color entirely disappears. The strength of this solution is such that 1 c.c. is decolorized by 5 milligrams of sugar (*dextrose*), from which the percentage of sugar in any solution can be determined.

All the sugars, with the exception of chemically pure saccharose, may be tested for with this solution.

The Fermentation Test.—All the sugars with the exception of lactose undergo reduction to simpler compounds, mainly alcohol and carbon dioxid, under the action of the yeast plant, *Saccharomyces cerevisiæ*. The change with dextrose is expressed in the following equation:

$$\begin{array}{ccccc} C_6H_{12}O_6 & = & 2C_2H_6O & + & 2CO_2. \\ \text{Dextrose} & = & \text{Alcohol} & + & \text{Carbon Dioxid.} \end{array}$$

About 95 per cent. of the dextrose is so changed, the remaining 5 per cent. yielding secondary products—succinic acid, glycerin, etc. As a means of testing any solution for the presence of sugar this method may be adopted. It is generally very satisfactory. From the quantity of carbon dioxid and alcohol thus produced the quantity of sugar in the solution may be determined.

Levulose, or **fruit-sugar,** is found in association with dextrose as a constituent of many fruits. It is sweeter than dextrose and more soluble in both water and dilute alcohol. From alcoholic solutions it crystallizes in fine, silky needles, though it usually occurs in the form of a syrup.

Levulose is distinguished from dextrose by its property of turning the plane of polarized light to the left; the extent to which it does so, however, varies with the temperature and concentration of the solution. For this reason it is turned levulo-rotatory.

Under the influence of the yeast plant it slowly undergoes fermentation, yielding the same products as dextrose. It also has a reducing action on cupric hydroxid.

Galactose is obtained by boiling milk-sugar (lactose) with dilute sulphuric acid. In many chemic relations it resembles dextrose. It is less soluble in water, however, crystallizes more easily, and has a greater dextro-rotatory power. It also undergoes fermentation with the yeast plant.

3. **SACCHAROSES,** $C_{12}H_{22}O_{11}$.

Saccharose, or **cane-sugar,** is widely distributed throughout the vegetable world, but is especially abundant in sugar-cane, sorghum cane, sugar-beet, Indian corn, etc. It crystallizes in large monoclinic prisms. It is soluble in water and in dilute alcohol. Saccharose has no reducing power on cupric hydroxid, and hence its presence can not be detected by Fehling's solution. It is dextro-rotatory. Boiled with dilute mineral, as well as with organic acids, saccharose combines with water and undergoes a change in virtue of which it rotates the plane of polarized light to the left, and hence the product was termed *invert* sugar. This latter has been shown to be a mixture of equal quantities of levulose and dextrose. This inversion of saccharose through hydration and decomposition is expressed in the following equation:

$$\underset{\text{Saccharose}}{C_{12}H_{22}O_{11}} + \underset{\text{Water}}{H_2O} = \underbrace{\underset{\text{Levulose}}{C_6H_{12}O_6} + \underset{\text{Dextrose}}{C_6H_{12}O_6}}_{\text{Invert Sugar.}}$$

Saccharose is not directly fermentable by yeast, but through the specific action of a ferment, *invertin* or *invertase*, secreted by the yeast plant, or the inverting ferment of the small intestine, it undergoes inversion, as previously stated, after which it is readily fermented, yielding alcohol and carbon dioxid.

Lactose is the form of sugar found exclusively in the milk of the mammalia, from which it can be obtained in the form of hard, white, rhombic prisms united with one molecule of water. It is soluble in water, insoluble in alcohol and ether. It is dextro-rotatory. It reduces cupric hydroxid, but to a less extent than dextrose. Dilute acids decompose it into equal quantities of dextrose and galactose. Lactose is not fermentable with yeast, but in the presence of the lactic acid bacillus it is decomposed into lactic acid, and finally into butyric acid, as expressed in the following equation:

$$\underset{\text{Lactose}}{C_{12}H_{22}O_{11}} + \underset{\text{Water}}{H_2O} = \underset{\text{Lactic Acid.}}{4C_3H_6O_3}$$

$$\underset{\text{Lactic Acid}}{2C_3H_6O_3} = \underset{\text{Butyric Acid}}{C_4H_8O_2} + \underset{\substack{\text{Carbon}\\\text{Dioxid}}}{2CO_2} + \underset{\substack{\text{Free}\\\text{Hydrogen.}}}{2H_2}$$

Maltose is a transformation product of starch, and arises whenever the latter is acted on by malt extract or the diastatic ferments in saliva and pancreatic juice. The change is expressed by the following equation:

$$\underset{\text{Starch.}}{2C_6H_{10}O_5} + \underset{\text{Water.}}{H_2O} = \underset{\text{Maltose.}}{C_{12}H_{22}O_{11}}$$

Maltose crystallizes in the form of white needles, which are soluble in water and in dilute alcohol. It is dextro-rotatory. In the presence of ferments and dilute acids maltose undergoes hydration and decomposition, giving rise to two molecules of dextrose. It has a reducing action on cupric hydroxid. Fermentation is readily caused by yeast, but whether directly or indirectly by inversion is somewhat uncertain.

Osazones.—All the sugars which possess the power of reducing cupric hydroxid are capable of combining with phenyl-hydrazin, with the formation of compounds termed osazones. The osazones so formed are crystalline in structure, but have different melting-points, varying degrees of solubility and optic properties, all of which serve to detect the various sugars and to distinguish one from the other. Of the different osazones, phenyl-glucosazone is the most characteristic, and occurs in the form of long, yellow needles. It may be obtained from dextrose by the following method: To 50 c.c. of a dextrose solution add 2 gm. of phenyl-hydrazin and 2 gm. of sodium acetate, and boil for an hour. On cooling, the osazone crystallizes in the form of long, yellow needles.

THE FATS.

The fats constitute a group of organic bodies found in the tissues of both vegetables and animals. In the vegetable world they are largely found in fruits, seeds, and nuts, where they probably originate from a transformation of the carbohydrates. In the animal body the fats are found largely in the subcutaneous tissue, in the marrow of bones, in and around various internal organs and in milk. In these situations fat is contained in small, round or polygon-shaped vesicles, which are united by areolar tissue and surrounded by blood-vessels. At the temperature of the body the fat is liquid, but after death it soon solidifies from the loss of heat.

The fats are compounds consisting of carbon, hydrogen, and oxygen, of which the first is the chief ingredient, forming by weight about 75 per cent., while the last is present only in small quantity. The fat found in animals is a mixture, in varying proportions in different animals, of three neutral fats—*stearin*, *palmitin*, and *olein*. Each fat is a derivative of glycerin and the particular acid indicated by its name—*e. g.*, stearic acid, in the case of stearin, etc. The reaction which takes place in the combination of glycerin and the acid is expressed in the following equation:

$$\underset{\text{Glycerin.}}{C_3H_5(HO)_3} + \underset{\text{Stearic Acid.}}{(HC_{18}H_{35}O_2)_3} = \underset{\text{Stearin.}}{C_3H_5(C_{18}H_{35}O_2)_3} + \underset{\text{Water.}}{3H_2O.}$$

Hence, strictly speaking, the fats are compound ethers, in which the hydrogen of the organic acid is replaced by the trivalent radicle, tritenyl, C_3H_5.

Stearin, $C_3H_5(C_{18}H_{35}O_2)_3$, is the chief constituent of the more solid fats. It is solid at ordinary temperatures, melting at 55° C., then solidifying again as the temperature rises, until at 71° C. it melts permanently. It crystallizes in square tables.

Palmitin, $C_3H_5(C_{16}H_{31}O_2)_3$ is a semifluid fat, solid at 45° C. and melting at 62° C. It crystallizes in fine needles, and is soluble in ether.

Olein, $C_3H_5(C_{18}H_{33}O_2)_3$, is a colorless, transparent fluid, liquid at ordinary temperatures, only solidifying at 0° C. It possesses marked solvent powers, and holds stearin and palmitin in solution at the temperature of the body.

Saponification.—When subjected to the action of superheated steam, a neutral fat is saponified—*i. e.*, decomposed into glycerin and the particular acid indicated by the name of the fat used: *e. g.*, stearic, palmitic, or oleic. The reaction is expressed as follows:

$$\underset{\text{Olein.}}{C_3H_5(C_{18}H_{33}O_2)_3} + \underset{\text{Water.}}{3H_2O} = \underset{\text{Glycerin.}}{C_3H_5(HO)_3} + \underset{\text{Oleic Acid.}}{3(C_{18}H_{34}O_2)}$$

The fat acids thus obtained are characterized by certain chemic features, as follows:

Stearic acid is a firm, white solid, fusible at 69° C. It is soluble in ether and alcohol, but not in water.

Palmitic acid occurs in the form of white, glistening scales or needles, melting at 62° C.

Oleic acid is a clear, colorless liquid, tasteless and odorless when pure. It crystallizes in white needles at 0° C.

If this saponification takes place in the presence of an alkali—*e. g.*, potassium hydroxid or sodium hydroxid—the acid produced combines at once with the alkali to form a salt known as a soap, while the glycerin remains in solution. The reaction is as follows:

$$\underset{\text{Potassium.}}{3KHO} + \underset{\text{Oleic Acid.}}{(C_{18}H_{34}O_2)_3} = \underset{\text{Potassium Oleate.}}{3(KC_{18}H_{33}O_2)} + \underset{\text{Water.}}{3H_2O}$$

All soaps are, therefore, salts formed by the union of alkalies and fat acids. The sodium soaps are generally hard, while the potassium soaps are soft. Those made with stearin and palmitin are harder than those made with olein. If the soap is composed of lead, zinc, copper, etc., it is insoluble in water.

Emulsification.—When a neutral oil is vigorously shaken with water or other fluid, it is broken up into minute globules that are more or less permanently suspended; the permanency depending on the nature of the liquid. The most permanent emulsions are those made with soap solutions. The process of emulsification and the part played by soap can be readily observed by placing on a few cubic centimeters of a solution of sodium carbonate (0.25 per cent.) a small quantity of a perfectly neutral oil to which has been added 2 or 3 per cent. of a fat acid. The combination of the acid and the alkali at once forms a soap. The energy set free by this combination rapidly divides the oil into extremely minute globules. A spontaneous emulsion is thus formed.

THE PROTEINS.

The proteins constitute a group of organic bodies which are found in both vegetable and animal tissues. Though present in all animal tissues, they are especially abundant in muscles and bones, where they constitute 20 per cent. and 30 per cent. respectively. Though genetically related, and possessing many features in common, the different members of the protein group are distinguished by characteristic physical and chemic properties which serve not only for their identification, but for their classification into more or less well-defined groups.

Chemic Composition.—A chemic analysis of proteins shows that they consist of carbon, hydrogen, oxygen, nitrogen and sulphur, though the percentage of each of these elements varies somewhat in the different proteins.

A certain number of proteins contain phosphorus while almost all of them contain different inorganic salts in varying amounts. The average percentage composition of several proteins is shown in the following analyses:

	C.	H.	N.	O.	S.	
Egg-albumin,	52.9	7.2	15.6	23.9	0.4	(Würtz).
Serum-albumin,	53.0	6.8	16.0	22.29	1.77	(Hammersten).
Casein,	52.3	7.07	15.91	22.03	0.82	(Chittenden and Painter).
Myosin,	52.82	7.11	16.77	21.90	1.27	(Chittenden and Cummins).

The molecular composition of the proteins is not definitely known and the formulæ which have been suggested are therefore only approximative. Leow assigns to albumin the formula $C_{72}H_{112}N_{18}O_{22}S$, while Schützenberger raises the numbers to $C_{240}H_{392}N_{65}O_{75}S_3$, either of which shows that the proteid molecule is extremely complex.

Structure of the Protein Molecule.—From the large size of the protein molecule as indicated by its chemic composition it might be inferred that its structure was equally complex. This modern investigation has shown to be the case.

When any one of the typical proteins, found in animal or vegetable tissues, is hydrolysed by acids, alkalies and animal ferments under appropriate conditions, it can be resolved through a series of descending stages into relatively simple nitrogen-holding bodies termed *amino-acids* and *diamino-acids*, of which somewhat more than twenty have been isolated and their properties determined. The principal amino-acids are as follows: Glycocoll, alanin, leucin, isoleucin, amino-isovalerianic acid, serin, aspartic acid, glutamic acid, phenylalanin, tyrosin, prolin, tryptophan. The principal diamino-acids are as follows: Ornithin, lysin, histidin, arginin, cystin.

The protein molecule is therefore structurally complex. The manner in which these elementary compounds are arranged, united or grouped in any given protein, is practically unknown. More or less successful attempts have been made at the reconstruction of the protein molecule by synthetic methods, by the union of two or more of the amino-acids. A number of such compounds have been formed by the union of from two to ten or more amino-acids, all of them exhibiting many of the protein reactions. Such bodies are termed polypeptids.

Physical Properties.—As a class the proteins are characterized by the following properties:

1. **Indiffusibility.**—None of the proteins normally assume the crystalline form, and hence they are not capable of diffusing through parchment or an animal membrane. Peptone, a product of the digestion of proteins, is an exception as regards its diffusibility. As met with in the body, all proteins are amorphous, but vary in consistence from the liquid to the solid state. The colloid character of the proteins permits of their separation and purification from crystalloid diffusible compounds by the process of dialysis.
2. **Solubility.**—Some of the proteids are soluble in water, others in solutions of the neutral salts of varying degrees of concentration, in strong acids and alkalies. All are insoluble in alcohol and ether.
3. **Coagulability.**—Under the influence of heat and animal ferments, some of the proteins readily pass from the soluble liquid state to the insoluble solid state, attended by a permanent alteration in their chemic composition. To this change the term coagulation has been given. The various proteins, however, coagulate at different temperatures. Proteins are capable of precipitation without losing their solubility by ammonium sulphate, sodium chlorid, and magnesium sulphate.
4. **Fermentability.**—In the presence of specific microörganisms—bacteria—the proteins, owing to their complexity and instability, are prone to undergo disintegration and reduction to simpler compounds. This decomposition or putrefaction occurs most readily when the conditions most favorable to the growth of bacteria are present—viz., a temperature varying from 25° C. to 40° C., moisture, and oxygen. The intermediate as well as the terminal products of the decomposition of the proteins are numerous, and vary with the composition of the protein and the specific physiologic action of the bacteria. Among the intermediate products is a series of alkaloid bodies, some of which possess marked toxic properties, known as ptomains. The toxic symptoms which frequently follow the ingestion of foods in various stages of putrefaction are to be attributed to these compounds. The terminal products are represented by hydrogen sulphid, ammonia, carbon dioxid, fats, phosphates, nitrates, etc.

Classification.—The protein compounds by virtue of their structural composition, their physical and chemic properties, permit of a provisional arrangement into groups as follows:

PROTAMINS.

These proteins are derived for the most part from the heads of the spermatozoa of fish. They take their names from the species of fish from which they are obtained, *e. g.*, salmin (salmon), sturin (sturgeon), scombrom, (mackerel), etc. Inasmuch as they respond to Piotrowski's test in a characteristic way they are regarded as true proteins. When subjected to hydrolysis they can be resolved into the diamino bodies, lysin, arginin and histidin, of which they constitute about 90 per cent., and a small number of the mono-amino-acids. Because of the fact that the diamino bodies, lysin, histidin and arginin contain 6 atoms of carbon they are known as the *hexone* bases. Inasmuch as the protamins contain practically but these three bodies, they are regarded as the simplest of all the proteins. Since a typical protein always yields on hydrolysis the hexone bases, in addition to a variable number of mono-amino-acids, it is believed that the usual protein is composed of a nucleus of the hexone bases to which is attached a variable number of mono-amino-acids. The proportions in which the bases exist in the nucleus and the proportions in which the amino-acids are united to the nucleus, vary in different proteins.

HISTONS.

The proteins embraced in this class comprise a series of compounds which are somewhat more complex than the protamins and less complex than the typical proteins; for on hydrolysis they not only yield the hexone bases but in addition a certain number of amino-acids. They are, therefore, intermediate in structural composition between the protamins and the usual proteins. Their protein character is indicated by their reaction to Millon's reagent and to Piotrowski's test. The histons are usually found in combination with nucleic acid, in the spermatozoa of most animals and especially in fish, and in the coloring matter (the hemoglobin) of the red corpuscles. The proteins of the tissues usually contain from 25 to 30 per cent. of histons.

ALBUMINS.

The members of this group are soluble in water, in dilute saline solutions, and in saturated solutions of sodium chlorid and magnesium sulphate. They are coagulated by heat, and when dried form an amber-colored mass.

(*a*) **Serum-albumin.**—This most important protein is found in blood, lymph, chyle, and some tissue fluids. It is obtained readily by precipitation from blood-serum, after the other proteins have been removed, on the addition of ammonium sulphate. When freed from saline constituents, it presents itself as a pale, amorphous substance, soluble in water and in strong nitric acid. It is coagulated at a temperature of 73° C., as well as by various acids—*e. g.*, citric, picric, nitric, etc. It has a rotatory power of —62.6°.

(*b*) **Egg-albumin.**—Though not a constituent of the human body, egg-albumin resembles the foregoing in many respects. When obtained in the solid form from the white of the egg, it is a yellow mass without taste or odor. Though similar to serum-albumin, it differs from it in being precipitated by ether, in coagulating at 54° C., and in having a lower rotatory power, —35.5°.

(*c*) **Lact-albumin.**—As its name implies, this protein is found in milk. It can be precipitated from milk-plasma by sodium sulphate after the precipitation of the other proteids by half saturation with ammonium sulphate. It slowly coagulates at 77° C.

(*d*) **Myo-albumin.**—This protein is found in muscle-plasma from which it subjects the plasma to fractional heat coagulation. At 73° C. myo-albumin coagulates.

GLOBULINS.

(*a*) **Serum-globulin or Paraglobulin.**—This protein, as its name implies, is found in blood-serum, though it is present in other animal fluids. When precipitated by magnesium sulphate or carbon dioxid, it presents itself as a flocculent substance, insoluble in water, soluble in dilute acids and alkalies, and coagulating at 75° C.

(*b*) **Fibrinogen.**—This protein is found in blood-plasma in association with serum-globulin and serum-albumin. It is also present in lymph-tissue fluids and in pathologic transudates. It can be obtained from blood-plasma which has been previously treated with magnesium sulphate on the addition of a saturated solution of sodium chlorid. It is soluble in dilute acids and alkalies, and coagulates at 56° C.

(*c*) **Para-myosinogen.**—This protein is a constituent of the muscle-plasma from which it can be precipitated by a temperature of 47° C.

(*d*) **Myosinogen.**—This protein is the chief constituent of the muscle-plasma and is of great nutritive value. During the living condition it is liquid, but after death it readily undergoes a chemic change and contributes to the formation of an insoluble protein known as myosin. It is soluble in dilute hydrochloric acid and dilute alkalies. It coagulates at 56° C.

(*e*) **Crystallin or Globulin.**—This is obtained by passing a stream of CO_2 through a watery extract of the crystalline lens.

SCLERO-PROTEINS (ALBUMINOIDS).

The sclero-proteins constitute a group of substances similar to the proteins in many respects, though differing from them in others. When obtained from the tissues, in which they form an organic basis, they are found to be amorphous, colloid, and when decomposed yield products similar to those of the true proteins. The principal members of this group are as follows:

(*a*) **Collagen, Ossein.**—These are two closely allied, if not identical, substances, found respectively in the white fibrous connective tissue and in bone. When the tendons of muscles, the ligaments, or decalcified bone are boiled for several hours, the collagen and ossein are converted into soluble gelatin, which, when the solution cools becomes solid.

(*b*) **Chondrigen.**—This is supposed to be the organic basis of the more permanent cartilages. When the latter are boiled, they yield a substance which gelatinizes on cooling, and to which the name chondrin has been given. Chondrin, however, is not a pure gelatin, but has associated with it a compound proteid known as chrondro-mucoid.

(*c*) **Elastin** is the name given to the substance composing the fibers of the yellow, elastic connective tissue.

(*d*) **Keratin** is the substance found in all horny and epidermic tissues, such as hairs, nails, scales, etc. It differs from most proteids in containing a high percentage of sulphur.

PHOSPHO-PROTEINS.

The two members of this group are distinguished by yielding on decomposition a protein which contains phosphorus. It was formerly regarded as a nuclein.

(*a*) **Caseinogen.**—This is the principal protein of milk, in which it exists in association with an alkali, and hence was formerly regarded as an alkali-albumin. It is *precipitated* by acetic acid and by magnesium sulphate. It is *coagulated* by rennet—that is, separated into an insoluble protein, casein or tyrein, and a soluble albumin. Calcium phosphate seems to be the natural alkali necessary to this process, for if it be removed by dialysis, or precipitated by the addition of potassium oxalate, coagulation does not take place.

(*b*) **Vitellin.**—Vitellin is a constituent of the vitellis or yolk of eggs. It differs from other proteins in the fact that it is semicrystalline in character. Though usually regarded as a nucleo-protein it is not definitely known whether or not it contains phosphorus in its composition.

CONJUGATED OR COMBINED PROTEINS.

The different members of this group are capable of being decomposed by chemic methods into a protein and a non-protein substance; *e. g.*, a coloring matter, a carbohydrate, or a nuclein. The chemic character of the non-protein substance furnishes the basis for the following classification:

CHROMO-PROTEINS.

(*a*) **Hemoglobin.**—Hemoglobin is the coloring matter of the red corpuscles, of which it constitutes about 94 per cent. It possesses the power of absorbing oxygen as it passes through the lung capillaries and of yielding it up to the tissues as it passes through the tissue capillaries. In the arterial blood it is known as oxyhemoglobin, and in the venous blood as deoxy- or reduced-hemoglobin. When hydrolysed by acids or alkalies, hemoglobin undergoes a cleavage into a protein, globin, and a pigment hematin.

(*b*) **Myohematin.**—Myohematin is a protein supposed to be present in muscle. It has never been isolated, hence its chemic features are unknown. Spectroscopic examination indicates that it is capable of absorbing and again yielding up oxygen. For this reason it is believed to be a derivative of hemoglobin.

GLUCO-PROTEINS.

(*a*) **Mucin.**—Mucin is the proteid which gives the mucus, secreted by the epithelial cells of the mucous membranes and related glands, its viscid, tenacious character. It is also a constituent of the intercellular substance of the connective tissues. It is readily precipitated by acetic acid. When heated with dilute acids, mucin undergoes a cleavage into a simpler proteid and a carbohydrate termed mucose, which is capable of reducing Fehling's solution.

(*b*) **Mucoids.**—The mucoids resemble the mucins though differing from them in solubility and in not being precipitable from alkaline solutions by acetic acid. They are found in the vitreous humor, white of egg, cartilage, and in other situations. They differ slightly one from the other in properties and chemic composition. They yield on decomposition a carbohydrate.

NUCLEO-PROTEINS.

The nucleo-proteins are obtained from the nuclei and cell-substance of tissue-cells. Chemically they are characterized by the presence of phosphorus in relatively large amounts. When hydrolysed, they separate into a protein and a nuclein. The nucleins derived from cell nuclei can be still further separated into a simpler protein and *nucleic* acid, which latter in turn yields phosphoric acid and the so-called purin bases, xanthin, hypoxanthin, adenin, and guanin. All nucleins which yield the purin bases are termed *true nucleins*.

PROTEIN DERIVATIVES.

The proteins of this group are derived from both albumins and globulins by the gradual action of dilute acids and alkalies, and may be regarded as compounds of a proteid with an acid or an alkali. They have been designated.

INFRA-PROTEINS.

(*a*) **Acid-albumin.**—This is formed when a native albumin is digested with dilute hydrochloric acid (0.2 per cent.) or dilute sulphuric acid for some minutes. It is precipitated by neutralization with sodium hydroxid (0.1 per cent. solution). After the precipitate is washed, it is found to be insoluble in distilled water and in neutral saline solutions. In acid solutions it is not coagulated by heat.

(*b*) **Alkali-albumin.**—This is formed when a native albumin is treated with a dilute alkali—*e. g.*, 0.1 per cent. of sodium hydroxid—for five or ten minutes. On careful neutralization with dilute hydrochloric acid, it is precipitated. It is also insoluble in distilled water and in saline solutions; it is not coagulable by heat.

PROTEOSES AND PEPTONES.

During the progress of the digestive process, as it takes place in the stomach and intestines, there is produced by the action of the gastric and pancreatic juices, out of the proteins of the food, a series of new proteins, known as proteoses and peptones. The chemic properties of these substances will be considered in connection with the process of digestion.

COAGULATED PROTEINS.

Although these proteins are not found as constituents of the animal organism, they possess much interest on account of their relation to prepared foods and to the digestive process. They are produced when solutions of egg-albumin, serum-albumin, or globulins are subjected to a temperature of 100° C. or to the prolonged action of alcohol. They are insoluble in water, in dilute acids, and in neutral saline solutions.

In this same group may be included also those coagulated proteins which are produced by the action of animal ferments on soluble proteins—*e. g.*, fibrin, myosin, casein.

(*a*) **Fibrin.**—Fibrin is derived from a soluble protein—fibrinogen—by the action of a special ferment. It is not present under normal circumstances in the circulating blood, but makes its appearance after the blood is withdrawn from the vessels and at the time of coagulation. It can also be obtained by whipping the blood with a bundle of twigs, on which it accumulates. When freed from blood by washing under water, it is seen to consist of bundles of white elastic fibers or threads. It is insoluble in water, in alcohol, and ether. In dilute acids it swells, becomes transparent, and finally is converted into acid-albumin. In dilute alkalies a similar change takes place, but the resulting product is an alkali-albumin. Fibrin possesses the property of decomposing hydrogen dioxid, H_2O_2

—*i. e.*, liberating oxygen, which accumulates in the form of bubbles on the fibrin. On incineration fibrin yields an ash which contains calcium phosphate and magnesium phosphate.

(*b*) **Myosin.**—Myosin develops in muscles after death and is the cause of the stiffening of the muscles. It has been regarded as a derivative of the soluble protein myosinogen alone, but there is evidence that in its formation both paramyosinogen and myosinogen take part. It is not definitely known whether this is the result of the action of a special ferment or not.

(*c*) **Casein.**—Casein is derived from the chief protein of milk—caseinogen—by the action of a special ferment known as rennin or chymosin. This ferment is a constituent of gastric juice.

The Color Reactions of Proteins.—When proteins are present in solution, they may be detected by the following color reactions—viz.:

1. Xanthoproteic. The solution is boiled with nitric acid for several minutes, when the proteid assumes a light yellow color. After the solution has cooled, the addition of ammonia changes the color to an orange or amber-red due to the presence of phenylalanin and tyrosin.
2. The rose-red reaction. The solution is boiled with acid nitrate of mercury (Millon's reagent) for a few minutes, when the coagulated proteid turns a purple-red color. This color is attributed to the presence of tyrosin.
3. The blue-violet reaction. A few drops of copper sulphate solution are first added to the protein solution, and then an excess of sodium hydroxid. A blue-violet color is produced, which deepens somewhat on heating, but no further change ensues. This is also known as Piotrowski's test: As this same color is developed with the substance biuret, it is also known as the *biuret reaction*. Biuret is formed by heating urea and driving off ammonia.

Precipitation Tests.—Proteins in solution may be *precipitated* by nitric acid, acetic acid and potassium ferrocyanid, picric acid, copper sulphate, tannin, alcohol, etc. As stated in a foregoing paragraph, certain of the proteins, *e. g.*, fibrinogen, caseinogen and myosinogen, will undergo, by the action of an animal ferment, a cleavage into a solid and a soluble portion. To this process the term *ferment coagulation* is applied. The solidification of proteins by the action of heat, is designated *heat coagulation.*

INORGANIC CONSTITUENTS.

The inorganic compounds and mineral constituents obtained from the solids and fluids of the body are very numerous, and, in some instances, quite abundant. Though many of the compounds thus obtained are undoubtedly derivatives of the tissues and necessary to their physical and physiologic activity, others, in all probability, are decomposition products, or transitory constituents introduced with the food. Of the inorganic compounds, the following are the most important:

WATER.

Water is the most important of the inorganic constituents, as it is indispensable to life. It is present in all the tissues and fluids without exception, varying from 99 per cent. in the saliva to 80 per cent. in the blood, 75 per cent. in the muscles to 2 per cent in the enamel of the teeth. The total quantity contained in a body weighing 75 kilograms (165 pounds) is 52.5 kilograms (115 pounds). Much of the water exists in a free condition, and forms the chief part of the fluids, giving to them their characteristic degree of fluidity. Possessing the capability of holding in solution a large number of inorganic as well as some organic compounds, and being at the same time diffusible, it renders an interchange of materials between all portions of the body possible. It aids in the absorption of new material into the blood and tissues, and at the same time it transfers waste products from the tissues to the blood, from which they are finally eliminated, along with the water in which they are dissolved. A portion of the water is chemically combined with other tissue constituents and gives to the tissues their characteristic physical properties. The consistency, elasticity, and pliability are, to a large extent, conditioned by the amount of water they contain. The total quantity of water eliminated by the kidneys, lungs, and skin amounts to about 3 kilograms (6½ pounds).

CALCIUM COMPOUNDS.

Calcium phosphate, $Ca_3(PO_4)_2$, has a very extensive distribution throughout the body. It exists largely in the bones, teeth, and to a slight extent in cartilage, blood, and other tissues. Milk contains 0.27 per cent. The solidity of the bones and teeth is almost entirely due to the presence of this salt, and is, therefore, to be regarded as necessary to their structure. It enters into chemic union with the organic matter, as shown by the fact that it can not be separated from it except by chemic means, such as hydrochloric acid. Though insoluble in water, it is held in solution in the blood and milk by the protein constituents, and in the urine by the acid phosphate of soda. The total quantity of calcium phosphate which enters into the formation of the body has been estimated at 2.5 kilograms. The amount eliminated daily from the body has been estimated at 0.4 gm., a fact which indicates that nutritive changes do not take place with much rapidity in those tissues in which it is contained.

Calcium carbonate, $CaCO_3$, is present in practically the same situations in the body as the phosphate, and plays essentially the same rôle. It is, however, found in the crystalline form, aggregated in small masses in the internal ear, forming the otoliths, or ear stones.

Though insoluble, it is held in solution by the carbonic acid diffused through the fluids.

Calcium fluorid, CaF_2, is found in bones and teeth.

SODIUM COMPOUNDS.

Sodium chlorid, NaCl, is present in all the tissues and fluids of the body, but especially in the blood, 0.6 per cent., lymph, 0.5, and pancreatic juice, 0.25 per cent. The entire quantity in the body has been estimated at about 200 gm. Sodium chlorid is of much importance in the body as it determines and regulates to a large extent the phenomena of diffusion which are there constantly taking place. This is illustrated by the fact that a solution of albumin placed in the rectum without the addition of this salt will not be absorbed. When the salt is added, absorption takes place. The ingested water is absorbed into the blood largely in consequence of the percentage of this salt which it contains. The normal percentage of sodium chlorid in the blood-plasma assists in maintaining the shape and structure of the red blood-corpuscles by determining the amount of water entering into their composition. The same is true of other tissue elements.

Sodium chlorid also influences the general nutritive process, increasing the disintegration of the proteins, as shown by the increased amount of urea excreted. During its existence in the body it undergoes chemic transformations or decompositions, yielding its chlorid to form the potassium chlorid of the blood-corpuscles and muscles and to form the hydrochloric acid of the gastric juice.

Sodium phosphate, Na_2HPO_4, is found in all solids and fluids of the body, to which, with but few exceptions, it imparts an alkaline reaction. This is especially true of blood, lymph, and tissue fluids generally. It is essential to physiologic action that all tissue elements should be bathed by an alkaline medium.

Sodium carbonate, Na_2CO_3, is generally found in association with the preceding salt. As it is an alkaline compound, it also assists in giving to the blood and lymph their characteristic alkalinity. In carnivorous animals the sodium phosphate is the more abundant, while in the herbivorous animals the sodium carbonate is the more abundant.

Sodium sulphate, Na_2SO_4, is present in many of the tissues and fluids, especially in the urine. Though introduced in the food, it is also, in all probability, formed in the body from the decomposition and oxidation of the proteids.

POTASSIUM COMPOUNDS.

Potassium chlorid, KCl, is met with in association with sodium chlorid in almost all situations in the body. It preponderates, however, in the tissue elements, especially in the muscle tissue, nerve tissue, and red corpuscles. The plasma with which these structures are bathed contains but a very small amount of this salt, but, as previously stated, a relatively large quantity of sodium chlorid. Though introduced to some extent in the food, it is very likely that it is also formed through the decomposition of the sodium chlorid.

Potassium phosphate, K_2HPO_4, is found in association with sodium phosphate in all the fluids and solids. As it has similar chemic properties, its functions are practically the same.

Potassium carbonate, K_2CO_3, is generally found with the preceding salt.

MAGNESIUM COMPOUNDS.

Magnesium phosphate, $Mg_3(PO_4)_2$, is found in all tissues, in association with calcium phosphate, though in much smaller quantity.

Magnesium carbonate, $MgCO_3$, occurs only in traces in the blood.

Both of these compounds have functions similar to the calcium compounds, and exist, in all probability, under similar conditions.

IRON COMPOUNDS.

Iron is a constituent of the coloring-matter of the blood. Traces, however, are also found in lymph, bile, gastric juice, and in the pigment of the eyes, skin and hair. The amount of iron contained in a body weighing 75 kilograms is about 3 gm. It exists under various forms—*e. g.*, ferric oxid, and in combination with organic compounds.

Chemic analysis thus shows that the chemic elements into which the compounds may be resolved by an ultimate analysis do not exist in the body in a free state, but only in combination, and in characteristic proportions, to form compounds whose properties are the resultant of those of the elements. Of the four principal elements which make up 97 per cent. of the body, O, H, N are extremely mobile, elastic, and possessed of great atomic heat. C, H, N are distinguished for the narrow range of their affinities, and for their chemic inertia. C possesses the great atomic cohesion. O is noted for the number and intensity of its combinations.

As the properties of the compounds formed by the union of elements must be the resultants of the properties of the elements themselves, it follows that the ternary compounds, starches, sugars, and fats must possess more or less inertia, and at the same time instability; while in the more complex proteids, in which sulphur and phosphorus are frequently combined with the four principal elements, molecular instability attains its maximum. As all the foregoing compounds possess in varying degrees the properties of inertia and instability, it follows that living matter must possess corresponding properties, and the capability of undergoing unceasingly a series of chemic changes, both of composition and decomposition, in response to the chemic and physical influences by which it is surrounded, and which underlie all the phenomena of life.

PRINCIPLES OF DISSIMILATION.

In addition to the previously mentioned compounds—viz., carbohydrates, fats, proteids, and inorganic salts—there is obtained by chemic analysis from the tissues and fluids of the body:

1. A number of organic acids, such as acetic, lactic, oxalic, butyric, propionic, etc., in combination with alkaline and earthy bases.
2. Organic compounds, such as alcohol, glycerin, cholesterin.
3. Pigments, such as those found in bile and urine.
4. Crystallizable nitrogenized bodies, such as urea, uric acid, xanthin, hippuric acid, creatin, creatinin, etc.

While some few of these compounds may possibly be regarded as necessary to the physiologic integrity of the tissues and fluids, the majority of them are to be regarded as products of dissimilation of the tissues and foods in consequence of functional activity, and represent stages in their reduction to simpler forms previous to being eliminated from the body.

CHAPTER III.

PHYSIOLOGY OF THE CELL.

A microscopic analysis of the tissues shows that they can be resolved into ultimate elements, termed cells, which may, therefore, be regarded as the primary units of structure. Though cells vary considerably in shape, size, and chemic composition in the different tissues of the adult body, they are, nevertheless, descendants from typical cells, known as embryonic or undifferentiated cells, examples of which are the leukocytes of the blood and lymph and the first offspring of the fertilized ovum. Ascending the line of embryonic development, it will be found that every organized body originates in a single cell—the ovum. As the cell is the elementary unit of all tissues, the function of each tissue must be referred to the function of the cell. Hence the cell may be defined as the primary anatomic and physiologic unit of the organic world, to which every exhibition of life, whether normal or abnormal, is to be referred.

Structure of Cells.—Though cells vary in shape and size and internal structure in different portions of the body, a typical cell may be said to consist mainly of a gelatinous substance forming the body of the cell, termed *protoplasm* or *bioplasm*, in which is embedded a smaller spheric body, the *nucleus*. The shape of the adult cell varies according to the tissue in which it is found; when young and free to move in a fluid medium, the cell assumes a spheric form, but when subjected to pressure, may become cylindric, fusiform, polygonal, or stellate. Cells vary in size within wide limits, ranging from $7.7\,\mu$ ($\frac{1}{3200}$ of an inch, the diameter of a red blood-corpuscle), to $135\,\mu$ ($\frac{1}{200}$ of an inch, the diameter of the large cells in the gray matter of the spinal cord). (See Fig. 2.)

The **cell protoplasm** consists of a soft, semifluid, gelatinous material, varying somewhat in appearance in different tissues. Though frequently homogeneous, it often exhibits a finely granular appearance under medium powers of the microscope. Young cells consist almost entirely of clear protoplasm. Mature cells contain, according to the tissue in which they are found, material of an entirely different character—*e. g.*, small globules of fat, granules of glycogen, mucigen, pigments, digestive ferments, etc. Under high powers of the microscope the cell protoplasm is found to be pervaded by a network of fibers, termed *spongioplasm*, in the meshes of which is contained a clearer and more fluent substance, the *hyaloplasm*. The relative amount of these two constituents varies in different cells, the proportion of hyaloplasm being usually greater in young cells. The arrangement of the fibers forming the spongioplasm also varies, the fibers having sometimes a radial direction, in others a concentric disposition, but most frequently being distributed evenly in all directions. In many cells the outer portion of the cell protoplasm undergoes chemic changes and is transformed into a thin, transparent, homogeneous membrane—the cell membrane—which completely incloses the cell substance. The cell membrane is permeable to water and watery solutions of various inorganic and organic substances. It is, however, not an essential part of the cell.

The **nucleus** is a small vesicular body embedded in the protoplasm near the center of the cell. In the resting condition of the cell it consists of a distinct membrane, composed of *amphipyrenin*, inclosing the nuclear contents. The latter consists of a homogeneous amorphous substance—the nuclear matrix—in which is embedded the nuclear network. It can often be seen that a portion of one side of the nucleus, called the pole, is free from this network. The main cords of the network are arranged as V-shaped loops about it. These main cords send out secondary branches or twigs, which, uniting with one another, complete the network. The nuclear cords are composed of granules of *chromatin*—so called because of its affinity for certain staining materials—held together by an achromatin substance known as *linin*. Besides the nuclear network, there are embedded in the nuclear matrix one or more small bodies composed of *pyrenin*, known as nucleoli. At the pole of the nucleus, either within or just without in the protoplasm, is a small body, the *centrosome*, or pole corpuscle.

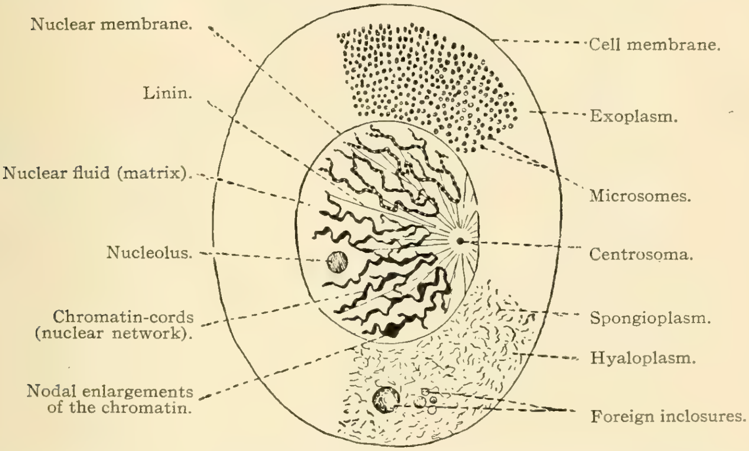
Nuclear membrane.
Linin.
Nuclear fluid (matrix).
Nucleolus.
Chromatin-cords (nuclear network).
Nodal enlargements of the chromatin.
Cell membrane.
Exoplasm.
Microsomes.
Centrosoma.
Spongioplasm.
Hyaloplasm.
Foreign inclosures.

FIG. 2.—DIAGRAM OF A CELL. Microsomes and spongioplasm are only partly drawn. —(*Stöhr.*)

Chemic Composition of the Cell.—The composition of living bioplasm is difficult of determination, for the reason that all chemic and physical methods employed for its analysis destroy its vitality, and the products obtained are peculiar to dead rather than to living matter. Moreover, as bioplasm is the seat of extensive chemic changes, it is not easy to determine whether the products of analysis are crude food constituents or cleavage or disintegration products. Nevertheless, chemic investigations have shown that even in the living condition bioplasm is a highly complex compound—the resultant of the intimate union of many different substances. About 75 per cent. of bioplasm consists of water and 25 per cent. of solids, of which the more important compounds are various nucleo-proteins (characterized by their large percentage of phosphorus), globulins, traces of lecithin, cholesterin, and possibly fat and carbohydrates. Inorganic salts, especially the potassium, sodium, and calcium chlorids and phosphates, are almost invariable and essential constituents.

MANIFESTATIONS OF CELL LIFE.

Growth, Nutrition, and Reproduction.—All cells exhibit the three fundamental properties of life—viz., growth, nutrition, reproduction. Growth is an increase in size. When newly reproduced all cells are extremely small, but in consequence of their organization and the character of their surrounding medium, they gradually grow until they attain the size characteristic of the adult state.

Nutrition is the maintenance of the physiologic condition of the cell and includes both growth and repair. So long as this is accomplished, the cells and the tissues which are formed by them continue to exhibit their functions or their characteristic modes of activity. Both growth and nutrition are dependent on the power which living material possesses of not only absorbing nutritive material from the surrounding medium, the lymph, but of subsequently assimilating it, organizing it, transforming it into material like itself and endowing it with its own physiologic properties.

In the physiologic condition the living material of the cell, the bioplasm, is the seat of a series of chemic changes which vary in degree from moment to moment in accordance with the degree of functional activity, and on the continuance of which all life phenomena depend. Some of these chemic changes are related to or connected with the molecules of the living material, while others are connected with the food material supplied to them. Of the chemic changes occurring within the molecules some are destructive, dissimilative or disintegrative in character, whereby the molecule is in part eventually reduced through a series of descending chemic stages to simpler compounds which, apparently of no use in the cell, are eliminated from it. It is, therefore, said that the living material undergoes molecular disintegration as a result of functional activity. To these changes the term *katabolism* is also applied. Other of these changes are constructive, assimilative or integrative in character, whereby a part at least of the food material is transformed through a series of ascending chemic stages into living material, and whereby it is repaired and its former physiologic condition restored. It is, therefore, said that the living material undergoes molecular integration as a preparation for functional activity. To these changes the term *anabolism* is also applied. The sum total of all chemic changes which go on in the cell, both anabolic and katabolic, is embraced in the general term *metabolism.* During the course of its physiologic activities the cell bioplasm produces materials of an entirely different character which vary with the cell, such as fat, glycogen, mucigen, pigments, ferments, etc., which are generally spoken of as metabolic products.

The food materials, sugar, fat and proteins, which are constituents of the fluids circulating in the tissue spaces, as above stated, are also reduced to simpler forms and the energy which they contain liberated in the form of heat. It is, therefore, said that the food also undergoes metabolism.

There is, however, much difference of opinion as to the extent to which the living material is metabolized and to the actual disposition of the food materials, and especially the proteins. Thus Voit contends that the tissue molecules are comparatively stable in composition and under ordinary conditions of nutrition do not undergo any material change during either rest or activity, and that metabolism is confined to the food materials occupying spaces in and around the living cell. The cause which initiates this metabolism is unknown, but is supposed to reside in the cell, if it is not a property of the cell itself. Because of the fact that but a very small amount, if any, of sugar or fat enters into the composition of bioplasm it is generally admitted that these foods are metabolized in the tissue spaces and in the manner just alluded to. The problem, however, is different in the case of the proteins. Voit contends, as previously stated, that the proteins of the tissue molecules, which he distinguishes as tissue proteins, do not metabolize and confines all protein metabolism to the food proteins circulating in the tissue spaces and which he distinguishes as circulating proteins. Even in starvation the tissue proteins, as such, do not metabolize until they have been dissolved in consequence of chemic changes and transformed into circulating protein.

Pflüger, however, asserts that the circulating proteins can not be metabolized but that they must first be built up into tissue proteins. The metabolism of protein is, therefore, confined, in this view, to the molecules of the living material. It is possible, however, that both views are correct and that in the physiologic condition the activity of the tissues is attended by a partial destruction of the tissue molecules which is followed in turn by construction during the subsequent rest, but that the greater part of the protein metabolism takes place outside the cell, though in contact with it.

Though the cell is, therefore, the seat of two opposing processes, assimilation and dissimilation, it retains under normal conditions an average physiologic state, and so long as this is the case it is in a condition of nutritive equilibrium and capable of performing its various functions.

Though the foregoing statements are applied to the individual cell they are equally applicable to the body as a whole, inasmuch as the organs and tissues of which it consists are composed of cells. The body grows in size and maintains its nutrition, by the introduction of food materials which are utilized in part, for the repair of the tissues which have undergone molecular disintegration in consequence of activity, and in part for the liberation of energy. As a result of the disintegration or the metabolism of tissue and food materials, products such as carbon dioxid, urea, etc., are formed which, apparently of no further use, are discharged from the body by eliminating organs as the kidney, lungs, skin, etc. Assimilation and dissimilation are constantly taking place. If the food assimilated and metabolized exactly replaces the tissues dissimilated and the food metabolized the body will retain a condition of nutritive equilibrium.

Physiologic Properties of Bioplasm.—All living bioplasm possesses properties which serve to distinguish and characterize it—viz., irritability, conductivity, and motility.

Irritability, or the power of reacting in a definite manner to some form of external excitation, whether mechanic, chemic, or electric, is a fundamental property of all living bioplasm. The character and extent of the reaction will vary, and will depend both on the nature of the bioplasm and the character and strength of the stimulus. If the bioplasm be muscle, the response will be a contraction; if it be gland, the response will be a secretion; if it be nerve, the response will be a sensation or some other form of nerve activity.

Conductivity, or the power of transmitting molecular disturbances arising at one point to all portions of the irritable material, is also a characteristic feature of all bioplasm. This power, however, is best developed in that form of bioplasm found in nerves, which serves to transmit, with extreme rapidity, molecular disturbances arising at the periphery to the brain, as well as from the brain to the periphery. Muscle bioplasm also possesses the same power in a high degree.

Motility, or the power of executing apparently spontaneous movements, is exhibited by many forms of cell bioplasm. In addition to the molecular movements which take place in certain cells, other forms of movement are exhibited, more or less constantly, by many cells in the animal body—*e. g.*, the waving of cilia, the ameboid movements and migrations of white blood-corpuscles, the activities of spermatozoids, the projection of pseudopodia, etc. These movements, arising without any recognizable cause, are frequently spoken of as spontaneous. Strictly speaking, however, all protoplasmic movement is the resultant of natural causes, the true nature of which is beyond the reach of present methods of investigation.

Reproduction.—Cells reproduce themselves in the higher animals in two ways—by direct division and by indirect division, or karyokinesis. In the former the nucleus becomes constricted, and divides without any special grouping of the nuclear elements. It is probable that this occurs only in disintegrating cells, and never in a physiologic multiplication. In division by karyokinesis (Fig. 3) there is a progressive rearranging and definite grouping of the nucleus, the result of which changes is the division of the centrosome, the chromatin, and the rest of the nucleus into two equal portions, which form the nuclei. Following the division of the nuclei, the protoplasm divides. The process may be divided into three phases:

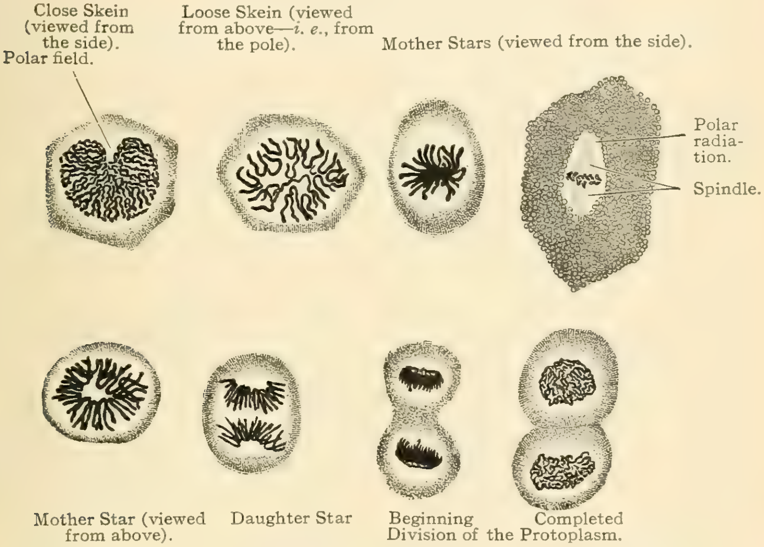
Close Skein (viewed from the side).
Polar field.
Loose Skein (viewed from above—*i. e.*, from the pole).
Mother Stars (viewed from the side).
Polar radiation.
Spindle.
Mother Star (viewed from above).
Daughter Star
Beginning
Completed
Division of the Protoplasm.

FIG. 3.—KARYOKINETIC FIGURES OBSERVED IN THE EPITHELIUM OF THE ORAL CAVITY OF A SALAMANDER. The picture in the upper right-hand corner is from a section through a dividing egg of Siredon pisciformis. Neither the centrosomes nor the first stages of the development of the spindle can be seen by this magnification. × 560.—(*Stöhr.*)

1. Prophase.—The centrosome, at first small and lying within the nucleus, increases in size and moves into the protoplasm, where it lies near the nucleus, surrounded by a clear zone, from which delicate threads radiate through an area known as the *attraction sphere*. The nucleus enlarges and becomes richer in chromatin. The lateral twigs of the chromatin cords are drawn in, while the main cords become much contorted. These cords have a general direction transverse to the long axis of the cell, and parallel to the plane of future cleavage. They are seen as V-shaped segments or loops, *chromosomes*, having their closed ends directed toward a common center, the *polar field*, while the other

ends interdigitate on the opposite side of the nucleus—the antipole. The polar field corresponds to the area occupied by the centrosome. This arrangement is known as the *close skein;* but as the process goes on, the chromosomes become thicker, shorter and less contorted, producing a much looser arrangement, known as the *loose skein.* During the formation of the loose skein, the centrosome divides into two portions, which move apart to positions at the opposite ends of the long axis of the nucleus. At the same time delicate achromatin fibers make their appearance, arranged in the form of a double cone, the apices of which correspond in position to the centrosomes. This is known as the *nuclear spindle.* During the prophase the nuclear membrane and the nucleoli disappear.

2. The Metaphase.—The two centrosomes are at opposite ends of the long axis of the nucleus, each surrounded by an attraction sphere, now called the *polar radiation.* The chromosomes become yet shorter and thicker, and move toward the equator of the nucleus, where they lie with their closed ends toward the axis, presenting the appearance, when seen from the poles, of a star—the so-called mother star, or monaster. While moving toward the equator of the nucleus, and often earlier, each chromosome undergoes longitudinal cleavage, the sister loops remaining together for a time. Upon the completion of the monaster, one loop of each pair passes to each pole of the nucleus, guided, and perhaps drawn by the threads of the nuclear spindle. The separation of the sister segments begins at their apices, and as the open ends are drawn apart they remain connected by delicate achromatin filaments drawn out from the chromosomes. This separation of the daughter chromosomes, and their movement toward the daughter centrosomes, is called *metakinesis.* As they approach their destination, we have the appearance of two stars in the nucleus—the *daughter stars*, or diasters.

3. Anaphase.—The daughter stars undergo, in reverse order, much the same changes that the mother star passed through. The chromosomes become much convoluted, and perhaps united to one another, the lateral twigs appear, and the chromatin resumes the appearance of the resting nucleus. The nuclear spindle, with most of the polar radiation, disappears, and the nucleoli and the nuclear membrane reappear, thus forming two complete daughter nuclei. Meanwhile the protoplasm becomes constricted midway between the young nuclei. This constriction gradually deepens until the original cell is divided, with the formation of two complete cells.

CHAPTER IV.

HISTOLOGY OF THE EPITHELIAL AND CONNECTIVE TISSUES.

1. EPITHELIAL TISSUE.

The **epithelial tissue** consists of one or more layers of cells resting on a homogeneous membrane, the other side of which is abundantly supplied with blood-vessels and nerves. The form of the epithelial cell varies in different situations, and may be flattened, cuboid, spheroid, or columnar. (See Figs. 4, 5, and 6.) The form of the cell in all instances is related to some specific function. When arranged in layers or strata, the cells are cemented together by an intercellular substance.

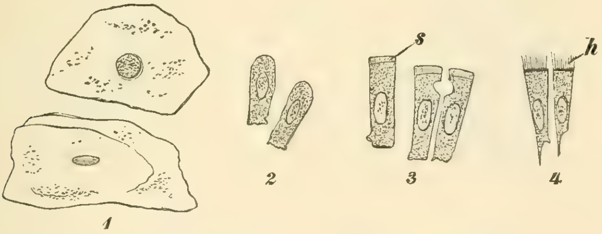

FIG. 4.—EPITHELIAL CELLS OF RABBIT, ISOLATED. × 560. 1. Squamous cells (mucous membrane of mouth). 2. Columnar cells (corneal epithelium). 3. Columnar cells, with cuticular border, *s* (intestinal epithelium). 4. Ciliated cells; *h*, cilia (bronchial epithelium).—(*Stöhr.*)

The epithelial tissue forms a continuous covering for the surfaces of the body. The external investment (the skin) and the internal investment (the mucous membrane, which lines the entire alimentary canal as well as associated body cavities) are both formed, in all situations, by the homogeneous basement membrane, covered with one or more layers of cells. The glands of the skin, the lungs and the glands in connection with the alimentary canal and the uro-genital apparatus are formed of the same elemental structures. All materials, therefore, whether nutritive, secretory, or excretory, must pass through epithelial cells before they can enter into the formation of the blood or be eliminated from it. The nutrition of the epithelial tissue is maintained by the nutritive material derived from the blood diffusing itself into and through the basement membrane. Chemically, the epithelial cells of the epidermis—hair, nails, etc.—are composed of an albuminoid material (keratin), a small quantity of water, and inorganic salts. In other situations, especially on the mucous membranes, the cells consist largely of mucin, in association with other proteins. The consistency of epithelium varies in accordance with external influences, such as the presence or absence of moisture, pressure, friction, etc. This is well seen in the skin of the palms of the hands and the soles of the feet—situations where it acquires its greatest density. In the alimentary canal, in the lungs, and in other cavities, where the reverse conditions prevail, the epithelium is extremely soft. Epithelial tissues also possess varying degrees of cohesion and elasticity—physical properties which enable them to resist considerable pressure and distention without having their physiologic integrity destroyed. Inasmuch as these tissues are poor conductors of heat, they assist in preventing too rapid radiation of heat from the body, and coöperate with other mechanisms in maintaining the normal temperature.

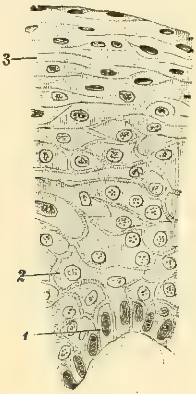

FIG. 5.—STRATIFIED SQUAMOUS EPITHELIUM (LARYNX OF MAN). × 240. 1. Columnar cells. 2. Prickle-cells. 3. Squamous cells.—(*Stöhr.*)

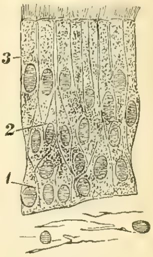

FIG. 6.—STRATIFIED CILIATED EPITHELIUM. × 560. From the respiratory nasal mucous membrane of man. 1. Oval cells. 2. Spindle-shaped cells. 3. Columnar cells.—(*Stöhr.*)

The physiologic activity of all epithelial tissue depends on a due supply of nutritive material derived from the blood, which not only maintains its nutrition, but affords those materials out of which are formed the secretions of the glands, whether of the skin or mucous membrane.

The cells lining the blood-vessels, the lymph-vessels, the peritoneal, pleural, pericardial, and other closed cavities are usually termed *endothelial* cells. These cells are flat, irregular in shape, with borders more or less wavy or sinuous in outline.

Functions of Epithelial Tissue.—In succeeding chapters the form, chemic composition, and functions of epithelial cells will be considered in connection with the functions of the organs of which they constitute a part. In this connection it may be stated in a general way that the functions of the epithelial tissues are:

1. To serve on the surface of the body as a protective covering to the

underlying structures which collectively form the true skin, thus protecting them from the injurious influences of moisture, air, dust, microörganisms, etc., which would otherwise impair their vitality. Wherever continuous pressure is applied to the skin, as on the palms of the hands and soles of the feet, the epithelium increases in thickness and density, and thus prevents undue pressure on the nerves of the true skin. The density of the epidermis enables it to resist, within limits, the injurious influence of acids, alkalies, and poisons.

2. To promote absorption. Inasmuch as the skin and mucous membranes cover the surfaces of the body, it is obvious that all nutritive material entering the body must first traverse the epithelial tissue. Owing to their density, however, the epithelial cells covering the skin play but a feeble rôle as absorbing agents in man and the higher animals. The epithelium of the mucous membrane of the alimentary canal, particularly that of the small intestine, is especially adapted, from its situation, consistency, and properties, to play the chief rôle in the absorption of new materials from the canal. The epithelium lining the air-vesicles of the lungs is engaged in promoting the absorption of oxygen and the exhalation of carbon dioxid.
3. To form secretions and excretions. Each secretory gland connected with the surfaces of the body is lined by epithelial cells, which are actively concerned in the formation of the secretion peculiar to the gland. Each excretory organ is similarly provided with epithelial cells, which are engaged either in the production of the constituents of the excretion or in their removal from the blood.

2. THE CONNECTIVE TISSUES.

The **connective tissues,** in their collective capacity, constitute a framework which pervades the body in all directions, and, as the name implies, serve as a bond of connection between the individual parts, at the same time affording a basis of support for the muscle, nerve, and gland tissues. The connective-tissue group includes a number of varieties, among which may be mentioned the areolar, adipose, retiform, white fibrous, yellow elastic, cartilaginous and osseous. Notwithstanding their apparent diversity, they possess many points of similarity. They have a common origin, developing from the same embryonic material; they have much the same structure, passing imperceptibly into one another, and perform practically the same functions.

Areolar Tissue.—This variety is found widely distributed throughout the body. It serves to unite the skin and mucous membrane to the structures on which they rest; to form sheaths for the support of blood-vessels, nerves, and lymphatics; to unite into compact masses the muscular tissue of the body, etc. Examined with the naked eye, it presents the appearance of being composed of bundles of fine fibers interlacing in every direction. In the embryonic state the elements of this form of connective tissue are united by a ground substance, gelatinous in character. In the adult state this substance shrinks and largely disappears, leaving intercommunicating spaces of varying size and shape, from which the tissue takes its name. When subjected to the action of various reagents, and examined microscopically, the bundles can be shown to consist of extremely delicate, colorless, transparent, wavy fibers, which are cemented together by a ground substance composed largely of mucin. Other fibers are also observed, which are distinguished by a straight course, a sharp, well-defined outline, a tendency to branch and unite with adjoining fibers, and to curl up at their extremities when torn. From their color and elasticity they are known as yellow elastic fibers. Distributed throughout the meshes of the areolar tissue are found flattened, irregularly branched, or stellate corpuscles, connective-tissue corpuscles, plasma cells, and granule cells.

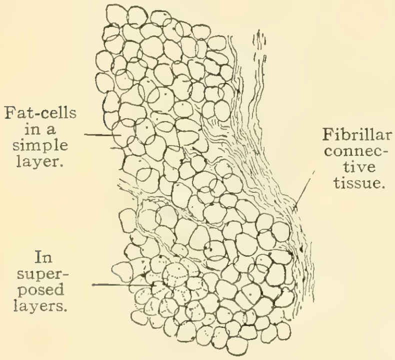

FIG. 7.—ADIPOSE TISSUE.—(*Stöhr.*)

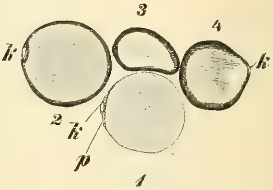

FIG. 8.—FAT-CELLS FROM THE AXILLA OF MAN. 1. The equator of the cell in focus. 2. The objective somewhat elevated. 3, 4. Forms changed by pressure. *p*. Traces of protoplasm in the vicinity of the flat nucleus *k*.—(*Stöhr.*)

Adipose Tissue.—This tissue, which exists very generally throughout the body, though found most abundantly beneath the skin, around the kidneys, and in the bones, is practically but a modification of areolar tissue. In these situations it presents itself in small masses or lobules of varying size and shape, surrounded and penetrated by the fibers of connective tissue. (See Fig. 7.) Microscopic examination shows that these masses consist of small vesicles or cells, round, elliptical or polyhedral in shape, depending somewhat on pressure. (See Fig. 8.) Each vesicle consists of a thin, colorless, protoplasmic membrane, thickened at one point, in which a nucleus can usually be detected. This membrane incloses a globule of fat, which during life is in the liquid state. It is composed of olein, stearin, and palmitin. The origin of the fat is to be referred to a retrograde change in the protoplasmic material of the connective-tissue cells. When this protoplasm becomes rich in carbon and hydrogen, it is speedily converted into fat, which makes its appearance in the form of minute drops in different portions of the cell. As the drops accumulate, at the expense of the cell protoplasm, they gradually coalesce, until there remains but a thin stratum of the protoplasm, which forms the wall of the vesicle. Adipose tissue may, therefore, be regarded as areolar tissue, in which, and at the expense of some of its elements, fat is stored for the future needs of the organism. A diminution of food, especially of fat and carbohydrates, is promptly followed by an absorption of fat by the blood-vessels and by its transference to the tissues, where it is either utilized for tissue construction or for oxidation purposes. In the situations in which adipose tissue is found it serves, by its chemic and physical properties, to assist in the prevention of a too rapid radiation of heat from the body, to give form and roundness, and to diminish angularities, etc.

Retiform and **adenoid tissue** are also modifications of areolar tissue. The meshes of the former contain but little ground substance, its place being taken by fluids; the meshes of the latter contain large numbers of lymph corpuscles.

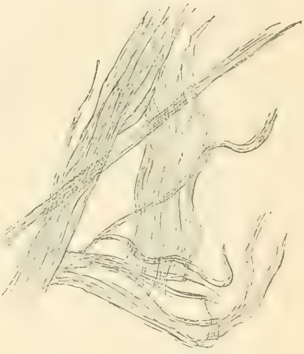

FIG. 9.—CONNECTIVE-TISSUE BUNDLES OF VARIOUS THICKNESSES OF THE INTERMUSCULAR CONNECTIVE TISSUE OF MAN. × 240.—(*Stöhr.*)

Fibrous Tissue.—This variety of connective tissue is widely distributed throughout the body. It constitutes almost entirely the ligaments around the joints, the tendons of the muscles, the membranes covering organs such as the heart, liver, nerve system, bones, etc. All fibrous tissue, wherever found, can be resolved into elementary bundles, which on microscopic examination are seen to consist of delicate, wavy, transparent, homogeneous fibers, which pursue an independent course, neither branching nor uniting with adjoining fibers. (See Fig. 9.) A small amount of ground substance serves to hold them together. Fibrous tissue is tough and inextensible, and in consequence is admirably adapted to fulfil various mechanical functions in the body. It is, however, quite pliant, bending easily in all directions. When boiled, fibrous tissue yields gelatin, a derivative of collagen.

Elastic Tissue.—The fibers of elastic tissue are usually associated in varying proportions with the white fibrous tissue; but in some structures—as the ligamentum nuchæ, the ligamenta subflava, the middle coat of the larger blood-vessels—the elastic fibers are almost the only elements present, and give to these structures a distinctly yellow appearance. The fibers throughout their course give off many branches, which unite with adjoining branches to form a more or less close network. As the name implies, these fibers are highly elastic, and are capable of being extended as much as 60 per cent. before breaking. (See Fig. 10.)

Cartilaginous Tissue.—This form of connective tissue differs from the preceding varieties chiefly in its density. As a rule, it is firm in consistency, though somewhat elastic. It is opaque, bluish-white in color, though in thin sections translucent. All cartilaginous tissues consist of connective-tissue cells embedded in a solid ground substance. According to the amount and texture of the ground substance, three principal varieties may be distinguished:

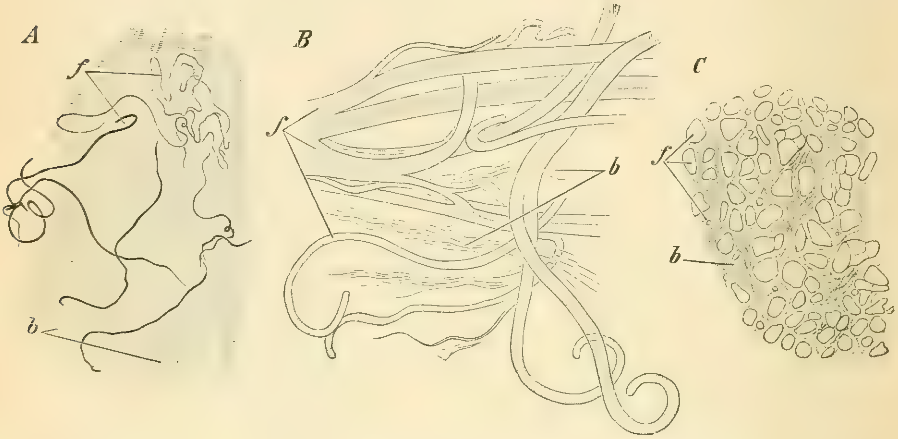

FIG. 10.—ELASTIC FIBERS. × 560. *A*. Fine elastic fibers, *f*, from intermuscular connective tissue of man; *b*, connective-tissue bundles swelled by treatment with acetic acid. *B*. Very thick elastic fibers, *f*, from ligamentum nuchæ of ox; *b*, connective-tissue bundles. *C*. From a cross-section of the ligamentum nuchæ of ox; *f*, elastic fibers; *b*, connective-tissue bundles.—(*Stöhr*.)

1. *Hyaline cartilage*, in which the cells, relatively few in number, are embedded in an abundant quantity of ground substance (Fig. 11). The body of the cells is in many instances distinctly marked off from the surrounding substance by concentric lines or fibers, which form a capsule for the cell. Repeated division of the cell substance takes place, until the whole capsule is completely occupied by daughter cells. The ground substance is pervaded by minute channels, which communicate on one hand with the spaces around the cells, and on the other with lymph-spaces in the connective tissue surrounding the cartilage. By means of these channels, nutritive fluid can permeate the entire structure. Hyaline cartilage is found on the ends of the long bones, where it enters into the formation of the joints; between the ribs and sternum, forming the costal cartilage, as well as in the nose and larynx.

2. *White fibro-cartilage*, the ground substance of which is pervaded by white fibers, arranged in bundles or layers, between which are scattered the usual encapsulated cells. (See Fig. 12.) White fibro-cartilage is tough, resistant, but flexible, and is found in joints where strength and fixedness are required. Hence it is present between the vertebræ, forming the intervertebral discs, between the condyle of the lower jaw and the glenoid fossa, in the knee-joint, around the margins of the joint cavities, etc. In these situations it assists in maintaining the apposition of the bones, in giving a certain degree of mobility to the joints, and in diminishing the effects of shock and pressure imparted to the bones.

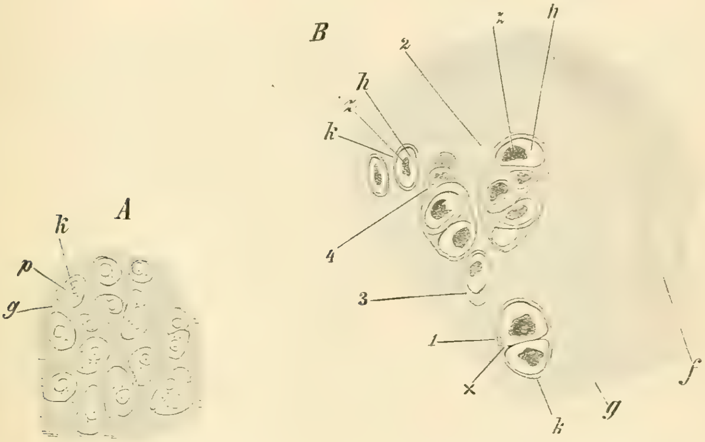

FIG. 11.—HYALINE CARTILAGE. × 240. *A*. Surface view of the ensiform process of frog, fresh; *p*, protoplasm of cartilage-cell, which entirely fills the lacuna; *k*, nucleus; *g*, hyaline matrix. *B*. Portion of cross-section of human rib-cartilage several days after death; examined in water: the protoplasm, *z*, of the cartilage-cells has withdrawn from the walls of the lacunæ, *h;* the nuclei are invisible. 1. Two cells within one capsule, *k; x*, a developing partition. 2. Five cartilage-cells within one capsule; the lowest cell has fallen out, and here only the empty space is seen. 3. Capsule cut obliquely, and apparently thicker on one side. 4. Capsule not cut, but showing the cell within. *g*. Hyaline matrix transformed into rigid fibers, *f*.—(*Stöhr*.)

3. *Yellow fibro-cartilage*, the ground substance of which is pervaded by opaque, yellow elastic fibers, which form, by the interlacing of their branches, a complicated network, in the meshes of which are to be found the usual corpuscles. (See Fig. 13.) As these fibers are elastic, they impart to the cartilage a very considerable degree of elasticity. Yellow fibro-cartilage is well adapted, therefore, for entering into the formation of the external ear, epiglottis, Eustachian tube, etc.—structures which require for their functional activity a certain degree of flexibility and elasticity.

Osseous Tissue.—Osseous tissue, as distinguished from bone, is a member of the connective-tissue group, the ground substance of which is permeated with insoluble lime salts, of which the phosphate and carbonate are the most abundant. Immersed in dilute solutions of hydrochloric acid, they can be converted into soluble salts and dissolved out. The osseous matrix left behind is soft and pliable. When boiled, it yields gelatin.

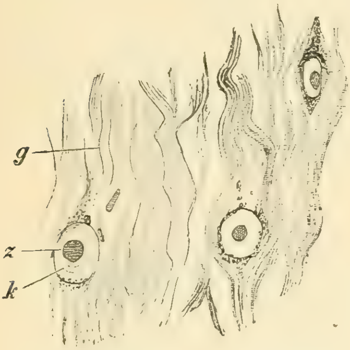

FIG. 12.—FROM A HORIZONTAL SECTION OF THE INTERVERTEBRAL DISC OF MAN. *g*. Fibrillar connective tissue. *z*. Cartilage-cell (nucleus invisible). *k*. Capsule surrounded by calcareous granules. × 240.—(*Stöhr*.)

A thin, transverse section of a decalcified bone, when examined microscopically, reveals a number of small, round, or oval openings, which represent transverse sections of canals which run through the bone, for the most part in a longitudinal direction, though frequently anastomosing with one another. These so-called Haversian canals in the living state contain blood-vessels and lymphatics. (See Fig. 14.)

Around each Haversian canal is a series of concentric laminæ, composed of white fibers. Between every two laminæ are found small cavities (lacunæ), from which radiate in all directions small canals (canaliculi), which communicate freely with one another. The Haversian canals, with their associated lacunæ and canaliculi, form a system of intercommunicating passages, which circulate lymph destined for the nourishment of bone. Each lacuna contains the bone corpuscle, which bears a close resemblance to the usual branched connective-tissue corpuscle, and whose function appears to be the maintenance of the nutrition of the bone.

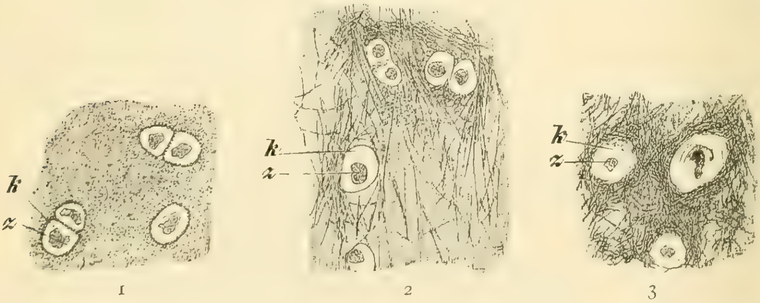

FIG. 13.—ELASTIC CARTILAGE. × 240. 1. Portion of section of vocal process (anterior angle) of arytenoid cartilage of a woman thirty years old; the elastic substance in the form of granules. 2 and 3. Portions of sections of epiglottis of a woman sixty years old; a fine network of elastic fibers in 2, a coarser network in 3. *z*. Cartilage-cell, nucleus not visible; *k*, capsule.—(*Stöhr*.)

The surface of every bone in the living state is invested with a fibrous membrane, the periosteum, except where it is covered with cartilage. The inner surface of this membrane is loose in texture, and supports a fine plexus of capillary blood-vessels and numerous protoplasmic cells—the osteoblasts. As this layer is directly concerned in the formation of bone, it is spoken of as the *osteogenetic* layer.

A section of a bone shows that it is composed of two kinds of tissue—compact and cancellated. The compact is dense, resembling ivory, and is found on the outer portion of the bone; the cancellated is spongy, and appears to be made up of thin, bony plates, which intersect one another in all directions, and is found in greatest abundance in the interior of the bones. The shaft of a long bone is hollow. This central cavity, which extends from one end of the bone to the other, as well as the interstices of the cancellated tissue, is filled in the living state with marrow. The marrow or medulla is composed of a connective-tissue framework supporting blood-vessels. In its meshes are to be found characteristic bone cells or osteoblasts, the function of which is supposed to be the formation of bone. In the long bones the marrow is yellow, from the presence in the connective-tissue corpuscle of fat globules, which arise through the transformation of the cell protoplasm. In the cancellated tissue, near the extremities of the long bones, this fatty transformation does not take place to the same extent, and the marrow appears red. The cells of the red marrow are believed to give birth indirectly to the red blood-corpuscles.

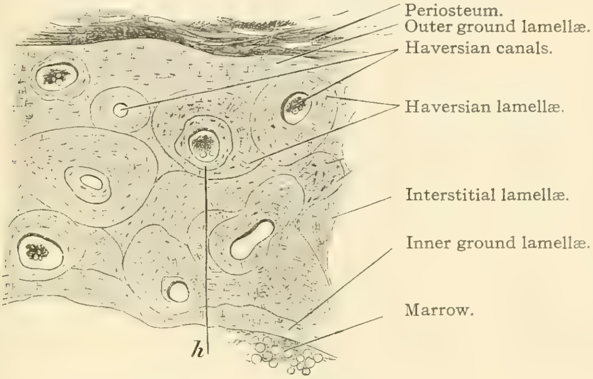

Fig. 14.—From a Cross-section of a Metacarp of Man. × 50. The Haversian canals contain a little marrow (fat-cells). Resorption line at *h*.—(*Stöhr*.)

Physical and Physiologic Properties of Connective Tissues.—Among the physical properties may be mentioned consistency, cohesion, and elasticity. Their *consistency* varies from the semiliquid to the solid state, and depends on the quantity of water which enters into their composition. Their *cohesion*, except in the softer varieties, is very considerable, and offers great resistance to traction, pressure, torsion, etc. In all the movements of the body, in the contraction of muscles, in the performance of work, the consistence and cohesion of these tissues play most important rôles. Wherever the various forms of connective tissue are found, their chemic composition and structure are in relation to their functions. If traction be the preponderating force, the structure becomes fibrous, as in ligaments and tendons, and the cohesion greatest in the longitudinal direction. If pressure be exerted in all directions, as upon membranes, the fibers interlace and offer a uniform resistance. When pressure is exerted in a definite direction, as on the extremities of the long bones, the tissue becomes expanded and cancellated. The lamellæ of the cancellated tissue arrange themselves in curves which correspond to the direction of the greatest pressure or traction. Extensibility is not a characteristic feature, except in those forms containing an abundance of yellow elastic fibers. The elasticity is an essential factor in many physiologic actions. It not only opposes and limits forces of traction, pressure, torsion, etc., but on their cessation returns the tissues or organs to their original condition. Elasticity thus assists in maintaining the natural form and position of the organs by counterbalancing and opposing temporarily acting forces.

The Skeleton.—The connective tissues in their entirety constitute a framework which presents itself under two aspects: (1) As a solid, bony skeleton, situated in the trunk and limbs, affording attachment for muscles and viscera; (2) as a fine, fibrous skeleton, found everywhere throughout the body, connecting the various viscera and affording support for the epithelial, muscle, and nerve tissues.

CHAPTER V.

THE PHYSIOLOGY OF MOVEMENT.

The Animal Body as a Machine for Doing Work.—Of the four phenomena presented by an animal, that which more immediately interests the physiologist is movement, for the reason that it is not only its most characteristic form of activity, and that which serves to distinguish it in the main from forms of vegetable life, but its solution affords an explanation of many physiologic processes occurring within the human body. It is also for this reason that movement constitutes for the most part the subject matter of physiologic experimentation.

The movements may be general as when the animal changes its position relatively to its environment as in the various acts of locomotion, or special as in the changes of relation of one part of the body with reference to another.

In the execution of these movements the animal, of necessity, meets with various forms of resistance, viz.: gravity, cohesion, friction, etc. When its different parts are applied or directed, either volitionally and in a determinate manner, or non-volitionally and in an indeterminate or reflex manner to the overcoming of these opposing forces in the environment, the animal may be said to be doing work.

In addition to these obvious external movements, a series of less obvious though no less characteristic internal movements are being exhibited by the various organs of the animal, *e.g.*, heart, lungs, stomach, intestines, bladder, etc.; and when these organs are applied to the overcoming of opposing forces or resistances, as they are from moment to moment in the performance of their functions, it may be said that they also are doing work. The coöperation of both external and internal organs is necessary, not only for the maintenance of the life of the animal but also for the accomplishment of work. In the conception of the animal body as a machine for doing work, the skeletal, the muscle and nerve tissues constitute a primary mechanism in which each bears a certain definite relation to the other. The internal organs collectively constitute a secondary mechanism in which each bears not only a definite relation to the other, but to the primary mechanism as well. The relation of skeletal, muscle and nerve tissue, are shown in Fig. 15.

General Considerations.—**The skeleton** is the passive framework of the body, the axial portions of which (the vertebral column, ribs, sternum and skull) impart more or less fixity and rigidity to the mechanism, while the appendicular portions (the bones of the arms and legs) impart extreme mobility. The bones of the arms and legs,

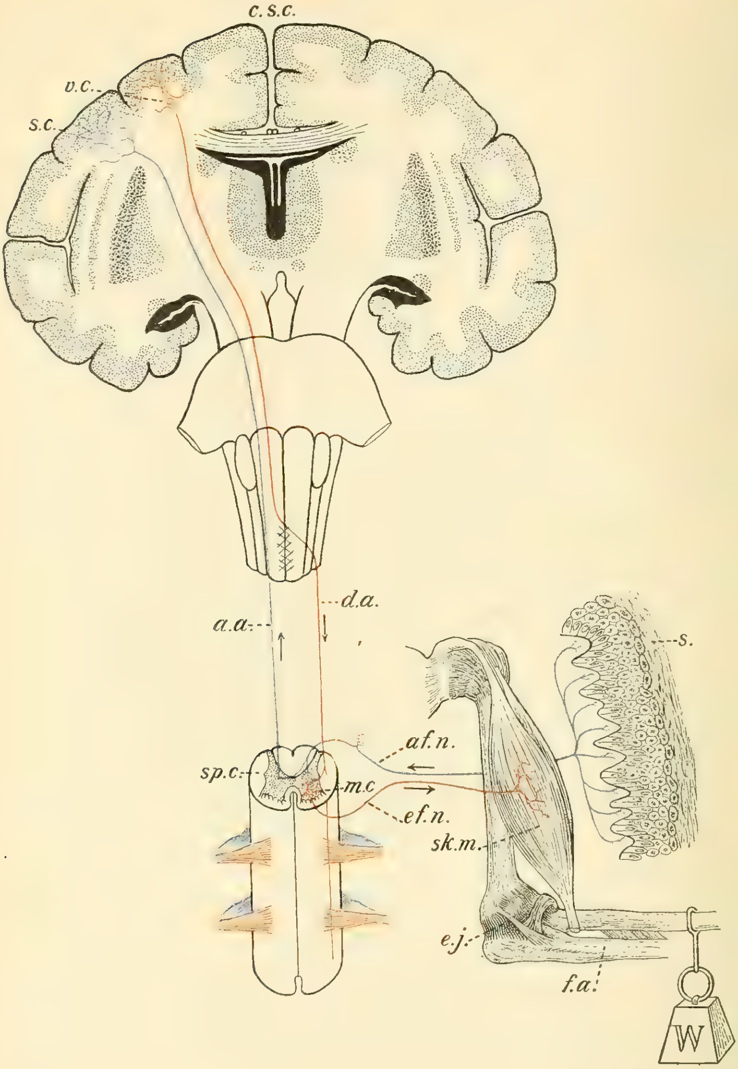

FIG. 15.—DIAGRAM SHOWING THE RELATON OF SKELETAL, MUSCLE AND NERVE TISSUES. (*G. Bachman.*) *f.a.* Bones of the forearm representing the skeletal tissue; *e.j.* the elbow joint, the fulcrum of the lever formed by the bones of the forearm; *W.* a weight acting in a downward direction and representing the passive force of gravity; *sk.m.* a skeletal muscle acting in an upward direction and the source of the active power to be applied to the lever; *sp.c.* transection of the spinal cord showing the relation of the white and the gray matter: *m.c.* a motor cell in the anterior horn of the gray matter; *ef.n.* an efferent nerve-fiber connecting the motor cell from which it arises with the skeletal muscle and contained in the ventral roots of the spinal nerves; *af.n.* an afferent nerve-fiber arising from the ganglion cell along its course and connecting the skin, *s.*, on the one hand with the spinal cord on the other hand and contained in the dorsal roots of the spinal nerves; *c.s.c.* coronal section of the cerebrum showing the relation of the gray to the white matter; *v.c.* a volitional or motor cell; *d.a.* a descending axon or nerve-fiber connecting the volitional cell from which it arises with the motor cell in the spinal cord; *s.c.* a sensor cell; *a.a.* an ascending axon or nerve-fiber connecting a receptive cell from which it arises (not shown in the diagram) with the sensor cell in the gray matter of the cerebrum. The nerve-fibers which pass outward from the spinal cord to the glands, blood-vessels, and the muscle walls of the viscera, have for the sake of simplicity been omitted from the diagram.

more especially, may be looked upon as constituting a system of levers, the fulcra of which, the points around which they move, lie in the joints.

That a lever may be effective as an instrument for the accomplishment of work, it must not only be capable of moving around its fulcrum, but it must, at the same time, be acted on by two opposing forces, one passive, the other active.

In the movements of the bony levers of the animal body, the *passive* forces to be overcome are largely those connected with the environment, *e. g.*, gravity, cohesion, friction, elasticity, etc. The *active* forces by which these are opposed and overcome through the mediation of the bony levers are found in the muscles attached to them.

The muscle tissue may therefore be regarded as the seat of those energies that impart movement to the levers. This tissue is arranged in masses of irregular shape and size, termed muscles. The majority of the muscles of the body are connected with the bones of the body in such a manner that by an alteration in their form, they can change not only the position of the bones with reference to one another, but also the individual's relation to surrounding objects. When the lever is applied to the overcoming of an opposing force, the muscle is said to be doing work.

Though consisting of a highly active tissue, muscles in themselves do not possess spontaneity of action, but require for the manifestation of their energy the stimulating influence of nerve energy or nerve impulses developed in, and transmitted by, nerve tissue to the muscles.

The nerve tissue is the seat of origin of those energies or impulses necessary to the physiologic excitation of the muscles. This tissue is partly arranged in masses contained in the cavities of the head and spinal column (the brain and spinal cord), forming the central organs of the nerve system, and partly in the form of cords or nerves, forming the peripheral organs of the nerve system; the latter connects the former, not only with the muscles, but with glands, blood-vessels, skin, mucous membranes, etc., as well.

A transection of the spinal cord shows that it is composed externally of white matter and internally of grey matter. The grey matter is arranged in the form of two crescents united in the median line by a transverse band or commissure forming a figure resembling the letter H. Though varying in shape in different regions of the cord, the grey matter in all situations presents on either side an anterior or ventral and a posterior or dorsal horn.

In the ventral horns of the grey matter are located nerve cells which not only generate, but under appropriate circumstances discharge, a form of energy termed a *nerve impulse*, which is transmitted by efferent nerve fibers arising from the cells, and by way of the ventral roots of the spinal nerves, to the muscles, glands, blood-vessels, and walls of the viscera with which they are directly or indirectly connected.

The arrival of the nerve impulse at once calls forth the form of activity characteristic of the structure excited.

Thus the muscle, for example, passes from the passive to the active state, that is, the muscle becomes shorter and thicker, and the bone to which it is attached is moved. This is at once followed by a return of the muscle to the passive state; that is, it lengthens, becomes narrower, and resumes its original form; the bone at the same time returns to its former position.

Coincident with this change of shape there is a liberation of heat and electricity. The nerve impulse which occasions this transformation of potential into kinetic energy is the normal or the physiologic stimulus. The muscle responding to the stimulus is said to be irritable or to possess irritability. The glands in response to the nerve impulse pour out a secretion. The blood-vessels and viscera change their caliber. These tissues, too, responding to the nerve impulse, are said to be irritable. The nerve cells of the spinal cord, however, do not possess spontaneity of action but require for their excitation the arrival of other nerve impulses. These may come, (1) from the periphery through afferent nerve fibers by way of the dorsal roots of the spinal nerves; and (2) from the brain as a result of an act of volition through descending axons or nerve fibers. In the first instance, the resulting movement taking place independently of volition, and in response to a peripheral or surface excitation, is termed a reflex movement; in the second instance, the resulting movement taking place in response to an act of volition is termed conventionally a volitional or voluntary movement.

In the case of reflex movements, the nerve impulses are primarily developed in specialized organs located in the skin or mucous membranes and as a result of the impact of various external agents, which for this reason are termed *stimuli*. The nerve impulses thus developed are transmitted by the afferent nerves to the nerve cells which are in turn excited to activity.

In the case of volitional muscle movements, the nerve impulses which cause the movement are discharged from certain motor or volitional nerve cells in the grey matter of the cerebrum and transmitted by descending axons or nerve fibers direct to the nerve cells in the spinal cord, by which they in turn are excited to activity.

The volitional movements are however the immediate or the more or less remote effects of sensations which have been evoked in the sense areas of the brain, by the arrival of nerve impulses coming through ascending axons or nerve fibers from peripheral sense organs, *e. g.*, skin, eye, ear, nose, tongue, and which have been developed by the impact of objects in the external world.

The nerve cells and their related nerve fibers, responding by the development and conduction of nerve impulses are also said to be irritable. The transformation of energy, however, manifests itself mainly as electricity and molecular motion. The animal body in its entirety may therefore be regarded as a machine for the transformation of potential energy into kinetic energy, viz.: heat and electricity, movements of muscles and bony levers, secretion, sensation and other forms of nerve activity. When muscles and bones are applied to the overcoming of opposing forces, mechanic work is accomplished. In the following chapters some of the problems connected with the activities of the skeletal, muscle and nerve tissues will be considered.

CHAPTER VI.

THE PHYSIOLOGY OF THE SKELETON.

The skeleton in its entirety determines the plan of organization of the animal body. Its axial portion is the foundation element and the center around which the appendicular portions are developed and arranged with a certain degree of conformity. The character and the arrangement of the bones of the axial portion endow the animal mechanism with a certain degree of fixity, combined with slight mobility, while the character and arrangement of the bones of the appendicular portions endow it with extreme mobility. The bones collectively constitute a system of levers, the fulcra of which lie in the points of union of the bones, and with which the animal is enabled to execute a variety of movements, to change its position relatively to its environment and overcome opposing forces. The structure and the chemic composition of the bones, consisting as they do of inorganic matter 67 per cent. and of organic matter 33 per cent. endow them with both rigidity and elasticity, physical properties which admirably adapt them to the character of the work necessitated by the environment and the organization of the animal. The rigidity of bone is considerable as compared with other hard and rigid materials. The breaking limit, in terms of the weight in kilos required to tear across a rod one square millimeter in cross-section of various materials is as follows: Cast iron 13; bone 12; oak 6.5; granite 1.9. The elasticity is about one-sixth that of wrought iron and twice that of oak parallel to the grain (MacAlister). In youth bones are quite elastic; in old age they are fragile because of a diminution of tissue and an increased porosity, and, therefore, at both periods less capable of functionating as effectively as in the middle period of life. The skeleton also serves for the attachment of muscles and affords support and protection to viscera.

For the manifestation of the activities of the animal it is essential that the relation of the various portions of the bony skeleton to one another shall be such as to permit of movement while yet retaining close apposition. This is accomplished by the mechanical conditions which have been evolved at the points of union of bones, and which are technically known as articulations or joints.

A consideration of the body movements involves an account of (1) the static conditions, or those states of equilibrium in which the body is at rest—*e. g.*, standing, sitting; (2) the dynamic conditions, or those states of activity characterized by movement—*e. g.*, walking, running, etc. In this connection, however, only those physical and physiologic peculiarities of the skeleton, especially in its relation to joints, will be referred to, which underlie and determine both the static and dynamic states of the body.

Structure of Joints.—The structures entering into the formation of joints are:

1. *Bones*, the articulating surfaces of which are often more or less expanded, especially in the case of long bones, and at the same time variously modified and adapted to one another in accordance with the character and extent of the movements which there take place.
2. *Hyaline cartilage*, which is closely applied to the articulating end of each bone. The smoothness of this form of cartilage facilitates the movements of the opposing surfaces, while its elasticity diminishes the force of shocks and jars imparted to the bones during various muscular acts. In a number of joints, plates or discs of white fibro-cartilage are inserted between the surfaces of the bones.
3. *A synovial membrane*, which is attached to the edge of the hyaline cartilage, entirely inclosing the cavity of the joint. This membrane is composed largely of connective tissue, the inner surface of which is lined by endothelial cells, which secrete a clear, colorless, viscid fluid—the synovia. This fluid not only fills up the joint-cavity, but, flowing over the articulating surfaces, diminishes or prevents friction.
4. *Ligaments*—tough, inelastic bands, composed of white fibrous tissue—which pass from bone to bone in various directions on the different aspects of the joint. As white fibrous tissue is inextensible but pliant, ligaments assist in keeping the bones in apposition, and prevent displacement while yet permitting of free and easy movements.

Classification of Joints.—All joints may be divided, according to the extent and kind of movements permitted by them, into (1) diarthroses; (2) amphiarthroses; (3) synarthroses.

1. *Diarthroses.*—In this division of the joints are included all those which permit of free movement. In the majority of instances the articulating surfaces are mutually adapted to each other. If the articulating surface of one bone is convex, the opposing but corresponding surface is concave. Each surface, therefore, represents a section of a sphere or a cylinder, which latter arises by rotation of a line around an axis in space. According to the number of axes around which the movements take place all diarthrodial joints may be divided into:

1. Uniaxial Joints.—In this group the convex articulating surface is a segment of a cylinder or cone, to which the opposing surface more or less completely corresponds. In such a joint the single axis of rotation, though nearly, is not exactly at right angles to the long axis of the bone, and hence the movements—flexion and extension—which take place are not confined to one plane.

Joints of this character—*e. g.*, the elbow, knee, ankle, the phalangeal joints of the fingers and toes—are, therefore, termed ginglymi, or hinge-joints. Owing to the obliquity of their articulating surfaces, the elbow and ankle are *cochleoid* or *screw-ginglymi.* Inasmuch as the axes of these joints on the opposite sides of the body are not coincident, the right elbow and left ankle are right-handed screws; the left elbow and right ankle, left-handed screws. In the knee-joint the form and arrangement of the articulating surfaces are such as to produce that modification of a simple hinge known as a *spiral hinge*, or *helicoid.* As the articulating surfaces of the condyles of the femur increase in convexity from before backward, and as the inner condyle is longer than the outer, and, therefore, represents a spiral surface, the line of translation or the movement of the leg is also a spiral movement. During flexion of the leg there is a simultaneous inward rotation around a vertical axis passing through the outer condyle of the femur; during extension a reverse movement takes place. Moreover, the slightly concave articulating surfaces of the tibia do not revolve around a single fixed transverse axis, as in the elbow-joint, for during flexion they slide backward, during extension forward, around a shifting axis, which varies in position with the point of contact.

In some few instances the axis of rotation of the articulating surface is parallel with rather than transverse to the long axis of the bone, and as the movement then takes place around a more or less conic surface, the joint is termed a *trochoid* or pulley—*e. g.*, the odonto-atlantal and the radio-ulnar. In the former the collar formed by the atlas and its transverse ligament rotates around the vertical odontoid process of the axis. In the latter the head of the radius revolves around its own long axis upon the ulna, giving rise to the movements of pronation and supination of the hand. The axis around which these two movements take place is continued through the head of the radius to the styloid process of the ulna.

2. Biaxial Joints.—In this group the articulating surfaces are unequally curved, though intersecting each other. When the surfaces lie in the same direction, the joint is termed an *ovoid* joint —*e. g.*, the radio-carpal and the atlanto-occipital. As the axes of these surfaces are vertical to each other, the movements permitted by the former joint are flexion, extension, adduction, and abduction, combined with a slight amount of circumduction; the latter joint permits of flexion and extension of the head, with inclination to either side. When the surfaces do not take the same direction, the joint, from its resemblance to the surfaces of a saddle, is termed a saddle-joint—*e. g.*, the trapezio-metacarpal. The movements permitted by this joint are also flexion, extension, adduction, abduction, and circumduction.

3. Polyaxial Joints.—In this group the convex articulating surface is a segment of a sphere, which is received by a socket formed by the opposing articulating surface. In such a joint, termed an *enarthrodial* or ball-and-socket joint—*e. g.*, the shoulder-joint, hip-joint—the distal bone revolves around an indefinite number of axes, all of which intersect one another at the center of rotation. For simplicity, however, the movement may be described as taking place around axes in the three ordinal planes—viz., a transverse, a sagittal, and a vertical axis. The movements around the transverse axis are termed flexion and extension; around the sagittal axis, adduction and abduction; around the vertical axis, rotation. When the bone revolves around the surface of an imaginary cone, the apex of which is the center of rotation and the base the curve described by the hand, the movement is termed circumduction.

2. *Amphiarthroses.*—In this division are included all those joints which permit of but slight movement—*e. g.*, the intervertebral, the interpubic, and the sacro-iliac joints. The surfaces of the opposing bones are united and held in position largely by the intervention of a firm, elastic disc of fibro-cartilage. Each joint is also strengthened by ligaments.

3. *Synarthroses.*—In this division are included all those joints in which the opposing surfaces of the bones are immovably united, and hence do not permit of any movement—*e. g.*, the joints between the bones of the skull.

The Vertebral Column.—In all static and dynamic states of the body the vertebral column plays a most essential rôle. Situated in the middle of the back of the trunk, it forms the foundation of the entire skeleton. It is composed of a series of superimposed bones, termed vertebræ, which increase in size from above downward as far as the brim of the pelvic cavity. Superiorly, it supports the skull; laterally, it affords attachment for the ribs, which in turn support the weight of the upper extremities; below, it rests upon the pelvic bones, which transmit the weight of the body to the inferior extremities. The bodies of the vertebræ are united one to another by tough elastic discs of fibro-cartilage, which, collectively, constitute about one-quarter of the length of the vertebral column. The vertebræ are held together by ligaments situated on the anterior and posterior surfaces of their bodies, and by short, elastic ligaments between the neural arches and processes. These structures combine to render the vertebral column elastic and flexible, and enable it to resist and diminish the force of shocks communicated to it.

The amphiarthrodial character of the intervertebral joints endows the entire column with certain forms of movement which are necessary to the performance of many body activities. While the range of movement between any two vertebræ is slight, the sum total of movement of the entire series of vertebræ is considerable. In different regions of the column the character, as well as the range of movement, varies in accordance with the form of the vertebræ and the inclination of their articular processes. In the cervical and lumbar regions extension and flexion are freely permitted, though the former is greater in the cervical, the latter in the lumbar region, especially between the fourth and fifth vertebræ. Lateral flexion takes place in all portions of the column, but is particularly marked in the cervical region. A rotatory movement of the column as a whole takes place through an angle of about twenty-eight degrees. This is most evident in the lower cervical and dorsal regions.

CHAPTER VII.

GENERAL PHYSIOLOGY OF MUSCLE-TISSUE.

The **muscle-tissue,** which closely invests the bones of the body and which is familiar to all as the flesh of animals, is the immediate cause of the active movements of the body. This tissue is grouped in masses of varying size and shape, which are technically known as muscles. The majority of the muscles of the body are connected with the bones of the skeleton in such a manner that, by an alteration in their form, they can change not only the position of the bones with reference to one another, but can also change the individual's relation to surrounding objects. They are, therefore, the active organs of both motion and locomotion, in contradistinction to the bones and joints, which are but passive agents in the performance of the corresponding movements. In addition to the muscle masses which are attached to the skeleton, there are also other collections of muscle-tissue surrounding cavities such as the stomach, intestine, blood-vessels, etc., which impart to their walls motility, and so influence the passage of material through them.

Muscles produce movement of the structures to which they are attached by the property with which they are endowed of changing their shape, shortening or contracting under the influence of a stimulus transmitted to them from the nervous system. Muscles are divided into:

1. Voluntary muscles, comprising those the activity of which is called forth by an act or effort of volition.
2. Involuntary muscles, comprising those the activity of which is entirely independent of the volition.

The voluntary muscles are also known from their attachment to the skeleton as skeletal, and from their microscopic appearance as striped or striated muscles. Though for the most part these muscles are *red*, there are certain muscles in man and other animals which are *pale* in color and in many muscles pale fibers are extensively distributed among the red fibers. The involuntary muscles, from their relation to the viscera of the body, are known also as visceral, and from their microscopic appearance as plain, smooth, or non-striated muscles.

THE VOLUNTARY OR SKELETAL MUSCLE.

All skeletal muscles consist of a central fleshy portion, the body or belly, provided at either extremity with a tendon in the form of a cord or membrane. The body is the active, contractile region, the source of the movement; the tendon is the inactive region, the passive transmitter of the movement to the bones.

A skeletal muscle is a complex organ consisting of a framework of connective tissue, supporting muscle-fibers, blood-vessels, nerves, and lymphatics. The general body of the muscle is covered by a dense layer of connective tissue, the epi-mysium, which blends with and partly forms the tendon. From the under surface of this covering, septa of connective tissue pass inward, dividing and grouping the fibers into larger and smaller bundles, termed fasciculi. The fasciculi, invested by a special sheath, the peri-mysium, are prismatic in shape and on cross-section present an irregular outline. The muscle-fibers composing the fasciculi are separated one from another and supported by a very delicate connective tissue, the endo-mysium. The connective tissue thus surrounding and penetrating the muscle binds the fibers into a distinct organ and affords support to all remaining structures (Fig. 16).

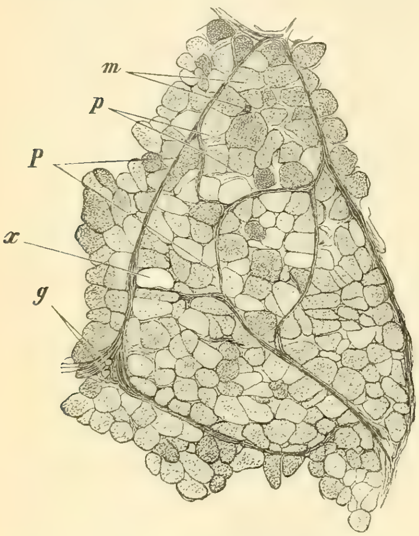

FIG. 16.—FROM A CROSS-SECTION OF THE ADDUCTOR MUSCLE OF A RABBIT. *P.* Perimysium, containing two blood-vessels, at *g*; *m*, muscle-fibers; many are shrunken and between them the endomysium, *p*, can be seen; at *x* the section of muscle-fiber has fallen out. × 60.—(*Stöhr.*)

Histology of the Skeletal Muscle-fiber.—The muscle-fiber is the ultimate anatomic units of the muscle system. The fibers for the most part are arranged parallel one to another and in a direction corresponding to the long axis of the muscle. They vary in length from 30 to 40 millimeters and in breadth from 20 to 30 micromillimeters. There are exceptional fibers, however, which have a much greater length. As the fibers have but a limited length in the vast majority of muscles, each end, more or less pointed or beveled, is united to adjoining fibers by cement. In this way a muscle is increased in length.

When examined with the microscope, the muscle-fiber is seen to be cylindric or prismatic in shape and to consist of a thin transparent membrane, the sarcolemma, in which is contained the true muscle or sarcous substance. The sarcolemma is elastic and adapts itself to all changes of form the sarcous substance undergoes. Beneath the sarcolemma there are several nuclei surrounded by granular material. Each fiber also presents a series of transverse bands alternately dim and bright which give to it a striated appearance. If the bright bands are examined with high magnifying powers, each one is seen to be crossed by a fine dark line which at the time of its discovery was regarded as the optic expression of a membrane attached laterally to the sarcolemma. It has since been resolved into a row of granules (Fig. 17).

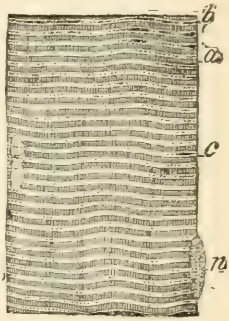

Fig. 17.—Muscle-fiber of a Rabbit. *a.* Dark band. *b.* Light band. *c.* Intermediate line. *n.* Nucleus. —(*Landois and Stirling.—Ranvier.*)

The muscle-fiber also presents a longitudinal striation which indicates that it is composed of finer elements placed side by side, termed fibrillæ. The fibrillæ extend throughout the entire length of the fiber, though they are not of uniform thickness (Fig. 18). That portion of the fibril corresponding in position to the dim band is thick, prismatic, or rod-like in shape, and termed a sarcostyle; that portion corresponding in position to the bright band is extremely thin and narrow and presents at its middle a slight enlargement or granule. The fibrillæ are embedded in a clear transparent fluid which, from its supposed nutritive character, is termed sarcoplasm. The diminution in caliber of the fibrillæ at different levels permits of the accumulation and storage of a larger amount of nutritive material than could otherwise be the case. It is for this reason that the fiber at these points presents a brighter appearance.

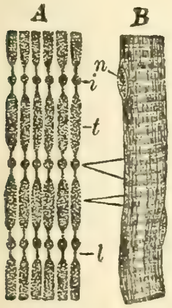

Fig. 18—*A.* Diagram of arrangement of the contractile substance according to the view of Rollett; the granular figures represent the contractile elements, the intervening light areas the sarcoplasm. *B.* Small muscle-fiber of man; the corresponding parts in the two figures are indicated; *t, i, l,* respectively the transverse, the intermediate, and lateral discs. *n.* Muscle nuclei.—(*Piersol.*)

When the muscle-fiber is examined under crossed Nichol prisms, the dim band appears bright and the bright band appears dim against a dark background, indicating that the former is doubly refracting or anisotropic, the latter singly refracting or isotropic.

The pale muscle fiber is histologically similar to the red. It is, however, somewhat larger, paler in color and does not contain so much muscle material. The transverse striation is closer and the nuclei are not so abundant.

The Blood-supply.—Muscles in the physiologic condition require for the maintenance of their activity a large amount of nutritive material. This is obtained directly from the lymph and indirectly from the blood furnished by the blood-vessels. The vascular supply to the muscles is very great and the disposition of the capillary vessels with reference to the muscle-fiber is very characteristic. The arterial vessels, after entering the muscle, are supported by the peri-mysium; in this situation they give off short, transverse branches, which immediately break up into a capillary network of rectangular shape within which the muscle-fibers are contained. The relation of the capillary vessel to the muscle-fiber is shown in Fig. 19.

The muscle-fiber, in intimate relation with the capillary, is bathed with lymph derived from it. Its contractile substance, however, is separated from the lymph by its own investing membrane, through which all interchange of nutritive and waste material must take place.

The nutritive material passes through the capillary wall into the lymph-space, then through the sarcolemma into the interior of the fiber, where it comes into relation with the living muscle material. The waste products arising in the muscle as a result of nutritive changes pass in the reverse direction first into the lymph and then into the blood, by which they are carried away to eliminating organs. Lymphatics are present in muscle, but confined to the connective tissue, in the spaces of which they take their origin.

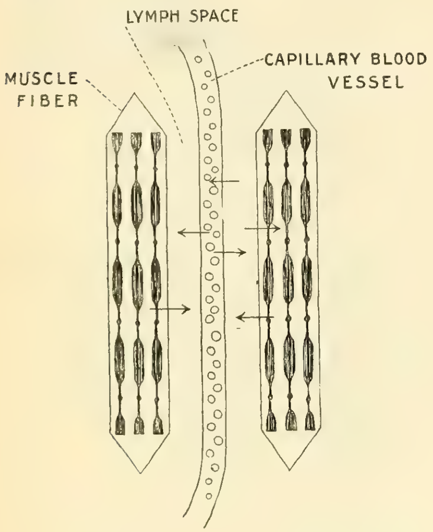

Fig. 19.—Relation of the Blood-vessel to the Muscle-fiber.

The Nerve-supply.—The nerves which carry the stimuli to a muscle enter near its geometric center. Many of the fibers pass directly to the muscle-fibers with which they are connected; others are distributed to blood-vessels. Every muscle-fiber is supplied with a special nerve-fiber except in those instances where the nerve-trunks entering a muscle do not contain as many fibers as the muscle. In such cases the nerve-fibers divide near their termination until the number of branches equals the number of muscle-fibers. The individual muscle-fiber is penetrated near its center by the nerve where it terminates; the ends being practically free from nerve influence. The stimulus that comes to the muscle-fiber acts primarily upon its center, the effect of which then travels in both directions to the ends. The manner in which the nerve-fibers terminate in muscle will be more fully described in connection with the histology of the nerve tissue.

CHEMIC COMPOSITION OF MUSCLE.

The chemic composition of living muscle is but imperfectly understood owing to the fact that shortly after death some of its constituents undergo a spontaneous coagulation and for the reason that the methods employed for analysis also tend to alter its composition. To human muscle, the following average percentage composition has been given:

Water,	73.5	
Proteins, including those of sarcolemma, connective-tissue, pigments,	18.02	
Gelatin,	1.99	
Fat,	2.27	
Extractives,	0.22	
Inorganic salts,	3.12.	(Halliburton.)

(The composition of muscles of different animals, consumed as foods, will be found in the chapter on Foods.)

When fresh muscle is freed from fat and connective tissue, frozen, rubbed up in a mortar, and expressed through linen, a slightly yellow syrupy alkaline or neutral liquid is obtained which has been termed muscle-plasma. This fluid at normal temperatures coagulates spontaneously, the phenomena resembling in many respects those observed in the coagulation of blood-plasma. The coagulum subsequently contracts and squeezes out an acid muscle-serum. The coagulated protein is known as myosin and belongs to the class of globulins. Inasmuch as it is not present in living muscle and only makes its appearance under conditions not strictly physiologic, it is regarded as a derivative of a pre-existing protein which has been termed myosinogen. According to Halliburton, the proteins of living muscle are four in number, distinguished by their varying solubilities in different salts and by the varying temperatures at which they coagulate. From muscle-plasma may then be obtained: (1) Paramyosinogen and (2) myosinogen, the former coagulating at 47° C., the latter at 56° C. It is myosinogen which is converted into myosin under the influence of some special ferment, though both enter into the formation of the muscle-clot. From the muscle-serum may also be obtained at 68° C. a globulin body termed myoglobulin and a small quantity of myoalbumin. Among the proteids may be mentioned hemoglobin, which gives the color to the muscles. Spectroscopic investigation reveals the presence of a special pigment, myohematin, which is supposed to have a respiratory function, inasmuch as its absorption bands change by oxidation and reduction.

Among the extractives containing nitrogen may be mentioned creatin, creatinin, xanthin, carnin, urea, uric acid, carnic acid, etc. Among the extractives free of nitrogen, glycogen, dextrose, inosite, lactic acid, fat, are the most important. Inorganic salts are relatively abundant, of which potassium is the most abundant among the bases, and phosphoric acid among the acids.

THE PHYSICAL AND PHYSIOLOGIC PROPERTIES OF MUSCLE-TISSUE.

Consistency.—The consistency of muscle-tissue during life varies considerably in accordance with different states of the muscle.

In a state of tension it is hard and resistant; in the absence of tension it is soft and fluctuating to the sense of touch. Tension alone gives rise to hardness.

Cohesion.—The cohesion of a muscle is largely dependent on the quantity of connective tissue it contains. A band of fresh human muscle one square centimeter in cross-section was able to resist a weight of 14 kilograms without rupture (MacAlister). Cohesion resists the forces of traction and pressure.

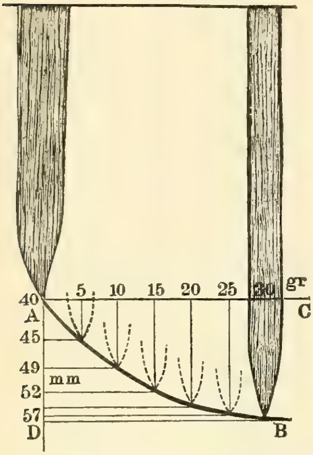

FIG. 20.—EXTENSION CURVE OF MUSCLE.—(*Gad.*)

Elasticity.—Muscle, in common with many other organic as well as inorganic substances, is capable of being extended beyond the normal length through the action of external forces and of resuming the normal length when these forces cease to act. All such bodies are said to be elastic; and the greater the variations between the natural and acquired lengths, the greater is their elasticity said to be. Muscle, therefore, possesses extensibility and elasticity.* If the muscle of a frog, preferably the sartorius, the fibers of which are arranged in a practically parallel manner, be fastened at one extremity by a clamp, and then extended by a series of successive weights which differ by a common increment, it will be found that the extensibility of muscle does not follow the law of elasticity as determined for inorganic bodies; *i. e.*, directly proportional to the weight and to the length of the body extended; but that while increasing in length with each successive weight, the increase is always in a diminishing ratio. Thus, for example, as shown in Fig. 20: The extension produced by 5 grams is 5 millimeters, that produced by 10 grams is only 4 millimeters more, and so on with additional weights until the increase in passing from 25 to 30 grams is only 1 millimeter. The extensibility is thus shown to be proportionately greater with small than with larger weights. It is, however, actually greater with the larger weights. The extension curve A B formed by joining the ends of the muscle approximates that of a parabola. The muscle in returning to its original length also shows a variation from the behavior of inorganic bodies. With the successive removal of the weights, the elasticity of the

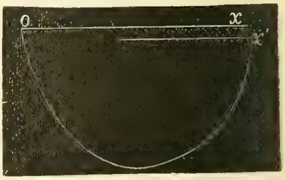

FIG. 21.—CURVE OF ELASTICITY PRODUCED BY CONTINUOUS EXTENSION AND RECOIL OF A FROG'S MUSCLE. *o x.* Abscissa before; *x'*, after extension.—(*Landois and Stirling.*)

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* By this latter term is here meant the power by virtue of which the muscle returns to its original length and is used synonymously with perfect retractibility.

muscle asserts itself with gradually increasing energy until its normal length is nearly, if not entirely, regained (Fig. 21). Though it is usually stated that the elasticity of muscle is incomplete, it must be borne in mind that the experiments have usually been made on muscles removed from the body, deprived of blood and nerve influences, and hence under abnormal conditions. It is highly probable that in the living body muscles possess perfect elasticity which enables them to completely return to their normal length after extension. The extension and elastic recoil of muscle depends on the maintenance of physiologic conditions. If the nutrition is impaired by fatigue, deficient blood-supply, or any pathologic condition, the elasticity is at once impaired.

Tonicity.—This is a property possessed by all muscles in the body in consequence of being stretched to a slight extent beyond their normal length. This may be due to the action of antagonistic muscles or to their mode of growth, the muscles growing somewhat more slowly than the bones to which they are attached. That muscles are so stretched is shown by the shortening which at once takes place when their tendons are divided. This muscle tonus or tension is closely connected with the elasticity and plays an important rôle in muscle contraction; being always on the stretch, the muscle loses no time in acquiring that degree of tension necessary to immediate action on the bone to which it is attached. The working power of a muscle is also increased by the presence, within limits, of some resistance to the act of contraction. According to Marey, the amount of work is considerably increased when the muscle energy is transmitted by an elastic body to the mass to be moved, while at the same time the shock of the contraction is lessened. The position of a passive limb is the resultant also of the elastic tension of antagonistic groups of muscles.

Another explanation for the tonicity of muscle is found in the fact that the skeletal muscles of the body receive continuously nerve impulses from the nerve cells of the spinal cord as a consequence of the arrival of nerve impulses reflected through afferent nerves from the tendons and muscles themselves. The stimulus here being the slight degree of extension and variations in extension to which the muscles are being subjected from moment to moment. That this is a considerable factor in the production of the tonus is shown by the effects which follow division of the afferent or dorsal roots of those spinal nerves coming from any given muscle group. With the division of the nerves the muscles relax and lose their usual tone. As a result of this slight but constant stimulation from the spinal cord, the metabolic changes of the muscle material are maintained at a certain level with a corresponding liberation of heat. The chief function of the tonicity would thus be the production of heat, other functions which the tone subserves being merely secondary.

Irritability, Contractility.—These are terms employed to denote that property of muscle-tissue by virtue of which it responds by a change of form, becoming shorter and thicker on the application of a stimulus. On the withdrawal of the stimulus the muscle again undergoes a reverse change of form, becoming longer and narrower, and returning to its original condition. All muscles which possess this capability are said to be irritable and contractile; and all agents which call forth this response of the muscle are termed stimuli. The rapid change of form which a highly irritable muscle undergoes in response to the action of a stimulus of short duration is usually termed a twitch or pulsation. With appropriate apparatus it can be shown that the muscle at the time of the twitch becomes warmer and exhibits electric phenomena. The muscle is therefore an apparatus for the conversion of potential into kinetic energy: viz., heat, electricity, and mechanic motion.

Though usually associated with the activity of the nerve system, and to some extent dependent on it, irritability is nevertheless an independent endowment of the muscle and persists for a longer or shorter period, as shown by many experiments, after all nerve connections have been destroyed. Among the proofs which may be presented in support of this view are the following: The introduction of the drug, curara, into the body of an animal produces in a short time complete paralysis. Experiment has shown that curara suspends the conductivity of the intramuscular terminations of the nerve-fiber and thus separates the muscle entirely from the nerve. Though the animal is incapable of executing a single movement, its muscles respond promptly on the application of a stimulus. Moreover, portions of muscles exhibit irritability in which there is no trace of nerve structure. This is the case with the ends of the sartorius muscle of the frog and the anterior end of the retractor muscle of the eyeball of the cat. These and other facts demonstrate the independence of muscle irritability.

In the living body irritability and nutritive activity, with which it is closely associated, are maintained by a due supply of oxygen, of nutritive material, the removal of waste products, and a normal temperature. The muscles of the cold-blooded animals, and especially the frog, retain their irritability for a much longer period after death than the muscles of the warm-blooded animals. This is the case also with the individual muscles after removal from the body of the animal. The reason for this is found in all probability in the difference in the rate of their nutritive activities and in the quantity of nutritive material stored up in their cells. The duration of the irritability of isolated muscles can be considerably prolonged by keeping them in a moist atmosphere.

Muscle Stimuli.—Though consisting of a highly irritable tissue, muscles do not possess spontaneity of action. They require for the manifestation of their characteristic activity the application of a stimulus. In the living body all contractions, at least of the skeletal muscles, occurring under normal or physiologic conditions are caused by the action of "nerve impulses" transmitted by the nerves from the central nerve system to the muscles. The nerve impulse is the normal or physiologic stimulus. After removal from the body and freed from nerve connections muscles can be excited to action by various agents of a mechanic, chemic, thermic, or electric nature. These are artificial or non-physiologic stimuli.

1. *Mechanic Stimuli.*—Cutting, pinching, sharply tapping the muscle will cause it to contract, providing the stimulus has sufficient intensity. With each stimulation a short, fleeting contraction ensues. If repeated with sufficient rapidity, a series of continuous but irregular pulsations are produced.
2. *Chemic Stimuli.*—Various chemic substances in solution will excite single or continuous pulsations if the strength of the solution is not such as to destroy at once the irritability. They owe their efficiency as stimuli to the rapidity with which they alter the composition of the muscle-substance. Among these may be mentioned solutions of potassium and sodium, weak solutions of the mineral and organic acids, ammonium vapor, distilled water, glycerin, and sugar.
3. *Thermic Stimuli.*—The application of a heated object, such as a hot wire, causes the muscle to rapidly contract.
4. *Electric Stimuli.*—The most efficient stimulus and the one least injurious to the tissue is the electric current. Either the constant or the induced current may be used.*

The Constant Current.—If the ends of the wires in connection with an electric cell be provided with non-polarizable electrodes and the latter placed on opposite ends of a freshly prepared sartorius muscle of a frog which has been previously curarized, it will be found on closing or making the circuit that the muscle will exhibit a short quick pulsation. During the actual passage of the current, especially if it is weak, there may be no apparent change in the muscle. If the current is strong, the muscle may, on the contrary, remain in a state of continuous contraction. With the opening or breaking of the current the muscle at once relaxes, or perhaps again contracts and then relaxes. The extent of the contraction depends mainly on the strength of the current, being greater with strong, less with weak currents. When the current is sufficiently strong to elicit both making and breaking contractions, it is found that the contraction occurring on the make or closure of the circuit is always greater than that occurring on the break or opening of the circuit. Moreover, it has been shown in many ways that the contraction occurring on the closure of the circuit has its origin at the point where the current is leaving the muscle—*i. e.*, in the immediate neighborhood of the negative pole or cathode—and propagates itself to the opposite extremity; while the contraction occurring on the opening of the circuit has its origin at the point where the current is entering the muscle, *i. e.*, in the neighborhood of the positive pole or anode.

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*Since the study of the physiologic properties of both muscle-tissue and nerve-tissue involves the employment of electricity as a stimulus, it becomes necessary for the student to familiarize himself with certain forms of apparatus by which it is generated, controlled, and applied. For the purpose of not interrupting the continuity of the text this information is embodied in an appendix. The facts therein contained should be mastered at this time by the student.

These facts can be readily demonstrated by destroying the irritability and contractility of one extremity of a muscle with parallel fibers such as the sartorius. On applying non-polarizable electrodes to the muscle as in Fig. 22, A, it will be found that when the circuit is made a contraction occurs which must, of course, have developed at the irritable cathodic region, for on the break of the circuit the muscle remains at rest. When the electrodes are applied as in Fig. 22, B, and the circuit made the muscle remains at rest, but on the break of the circuit a contraction occurs which must have developed at the irritable anodic region.

The Induced Current.—If the primary spiral of the inductorium be connected with an electric cell and the secondary spiral be connected with a muscle, it will be found that the current induced in the secondary circuit, both on the make and break of the primary, will also cause the muscle to sharply and rapidly pulsate if the two spirals are sufficiently near each other. Observation, however, makes it evident that the pulsation occurring with the break of the primary circuit is more energetic than that occurring with the make, a result the opposite of that obtained with the constant current. This is not due to any difference in the electricity, however, but to peculiarities in the construction of the inductorium. When the primary circuit is interrupted with sufficient frequency, as it can be by throwing into the circuit Neef's hammer or some other form of interrupter, the contractions excited by the induced currents may be made to succeed one another so rapidly that they become fused together, producing a *spasm* or *tetanus* of the muscle. The rapidity with which the induced current appears and disappears, its brief duration, the ease with which its strength can be regulated, combine to render it a most efficient stimulus for either muscle or nerve.

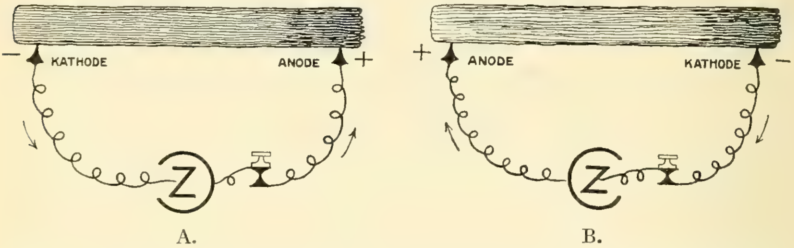

FIG. 22.—DIAGRAM TO SHOW THE EFFECT OF LOCAL INJURY ON THE IRRITABILITY OF A MUSCLE (*after Starling*). C Z an electric cell from which wires pass to non-polarizable electrodes, anode and kathode, in contact with a muscle, the injured end of which is more deeply shaded. The arrows indicate the direction of the current.

Conductivity.—All muscle protoplasm possesses conductivity.

The change excited in a muscle-fiber by the arrival of a nerve impulse is at once conducted with great rapidity in opposite directions to the end of the fibers; the advance of the excitation process is immediately succeeded by the contraction process, the change of form which constitutes the contraction. With the disappearance of the former, the latter also disappears and the muscle resumes its previous passive condition. There is no evidence, however, that the excitation process travels transversely—that is, into adjoining fibers—being prevented from doing so by the presence of the limiting membranes, the sarcolemmata. The fact that each muscle-fiber receives its own, or at least a branch of a nerve-fiber, and hence its own nerve impulse or stimulus, would also indicate that the excitation process can not be conducted longitudinally into adjoining fibers, or at least with sufficient rapidity for the purposes of ordinary muscle actions. Nevertheless if a long muscle, such as the sartorius, from a curarized frog be stimulated at one end with an induced electric current, the excitation and the contraction processes will be conducted with extreme rapidity to the opposite end of the muscle. The rapidity of conduction in human muscles has been estimated at from 10 to 13 meters per second, and in frog's muscle at from 3 to 4.5 meters per second. The contraction process, the thickening of the muscle, is termed the contraction wave. As it is the result of the excitation process and immediately succeeds it, its rate of conduction must be the same as that given above. With appropriate apparatus the duration of the wave at any given point has been shown to be, in the frog's muscle, one-tenth of a second and its length three-tenths of a meter.

PHENOMENA ATTENDING A MUSCLE CONTRACTION.

PHYSICAL PHENOMENA.

The most obvious change in a muscle during the contraction is that relating to its form. The muscle not only becomes shorter, but at the same time thicker. The extent to which it may shorten when unopposed may amount to 30 per cent. or more of its original length. The increase in thickness practically compensates for the diminution in length, for there is no observable diminution in volume. The change in form of the entire muscle results from a corresponding change of form of its individual fibers as determined by microscopic examination, each of which becomes shorter and thicker. The successive changes in both the muscle and the individual fibers are represented in Fig. 23.

When the contraction begins, the dim band increases and the bright band diminishes in width. This Engelmann attributes to the passage of fluid material from the bright into the dim band. At the time of relaxation there is a return of this material and the bands assume their original shape and volume. As the contraction wave reaches its maximum the optic properties of the bright and dim bands change. The former now becomes darker and less transparent until at the crest of the wave it assumes the appearance of a distinct dark band; the latter now becomes clear and bright in comparison. This change in the appearance of the fiber is due to an increase in refrangibility of the bright, and a decrease in the refrangibility of the dim band, coincident with the passage of the fluid from the former into the latter. There is at the height of the contraction a complete reversal in the positions of the striations. At a certain stage between the beginning and the crest of the wave the striæ almost entirely disappear, giving to the fiber an appearance of homogeneity. There is, however, no change in refractive power as shown by the polarizing apparatus. When the contraction wave has reached the stage of greatest intensity, there is a reversal of the above phenomena as the fiber returns to its former condition, that of relaxation.

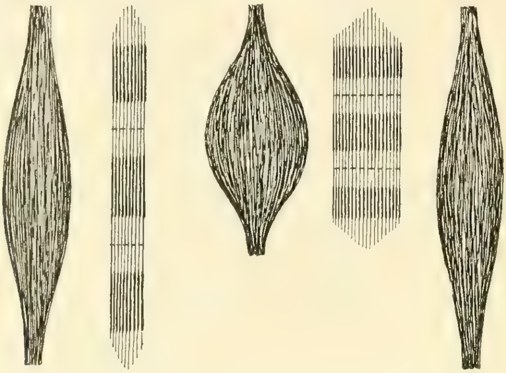

Fig. 23.—Showing the Changes in a Muscle and Muscle-fiber during Contraction.

Elasticity.—During the contraction of a muscle there is a greater or less alteration in its elasticity, as shown by the fact that it is extended to a greater degree by the same weight in the active than in the passive condition. The degree to which the extensibility is increased and the elasticity decreased is dependent on the amount of the resisting force. These facts, as determined experimentally, are represented in Fig. 24. Let A B and A b represent the length of the normal unweighted muscle, passive and active states respectively; the line B B′, the extension curve of the passive muscle produced by successive weights, 5, 10, 15, 20, 25, 30 grams, differing by a common increment; the line b B′, the extension curve of the active contracted muscle when weighted with the same weights; A′ B′ the length of the muscle when the weight is sufficiently great to prevent shortening. It will be observed from these facts that while the muscle is extended in both the passive and active states by corresponding weights, the extension during the latter is progressively greater, until with a given weight the length of the muscle is the same. Under such circumstances, there being no shortening of the muscle, the energy of its contraction manifests itself physically merely as tension. In the successive actions of the muscle represented in the same figure there is to be observed also a combination of a change of length and a change of tension, the ratio of the one to the other being determined by the amount of the supported weights. When the weight is slight in amount, the shortening of the muscle reaches a maximum and the tension a minimum; when the weight is large in amount, the reverse conditions obtain.

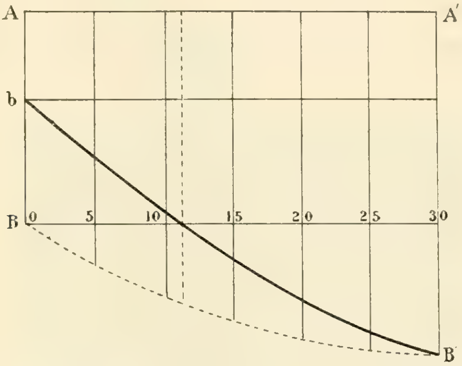

FIG. 24.—EXTENSION CURVES: B B′, of the resting; b B′, of the contracting muscle.

THE CONTRACTION PROCESS. METHODS OF INVESTIGATION.

The contraction of a muscle as it takes place in the living body and under normal physiologic conditions is a complex act persisting for a variable length of time in accordance with the number of stimuli transmitted to it in a given unit of time, and as determined experimentally is the resultant of the fusion of a greater or less number of separate and individual contractions or pulsations. To this enduring contraction the term *tetanus* has been given. With the aid of appropriate apparatus it has become possible to obtain and record single muscle contractions, to analyze and decompose them into their constituent elements, or to combine them in such a manner as to produce practically a normal physiologic tetanus. As in the experimental study of the phenomena of a muscle contraction it frequently becomes necessary to remove the muscle from the body of the animal, the muscles of warm-blooded animals are not well adapted for this purpose, owing to the rapid alteration in composition they undergo, with a consequent loss of irritability, when deprived of their normal blood-supply. The excised muscles of cold-blooded animals, particularly of the frog—in which, owing to the relatively slow rate of the nutritive activities, the irritability and contractility endure for a relatively long period of time, even though deprived of blood—are particularly valuable for experimental studies. The muscles generally employed are the gastrocnemius, the sartorius, and the hyoglossus. If kept at a normal temperature and moistened with 0.6 per cent. solution of sodium chlorid, such a muscle will contract for a long period of time on the application of any form of stimulus, but especially the electric.

Graphic Record of a Muscle Contraction.—Inasmuch as the changes in the form of a muscle during a single contraction take place with extreme rapidity, their succession, peculiarities, and time relations cannot be determined with any degree of accuracy by the unaided eye. This difficulty can largely be overcome by the employment of the graphic method, the principle of which consists in recording the movements by means of a pen on some appropriate moving and receiving surface. To accomplish this object the muscle is attached at one extremity by a clamp to a firm support, and at the other extremity to a weighted lever, which is, however, sufficiently light to enable it to take up, reproduce, and magnify its movements. The end of the lever provided with a pen is applied to a smooth surface, such as glazed paper on a cylinder or plate, and covered with lampblack. If the surface is stationary, the contraction is recorded as a vertical line; if it is placed in movement at a uniform rate by clockwork, the contraction is recorded in the form of a curve, the width of the arms of which will depend on the rate of movement. The time relations of the phases of the contraction can be obtained by placing beneath the lever a pen attached to an electro-magnet thrown into

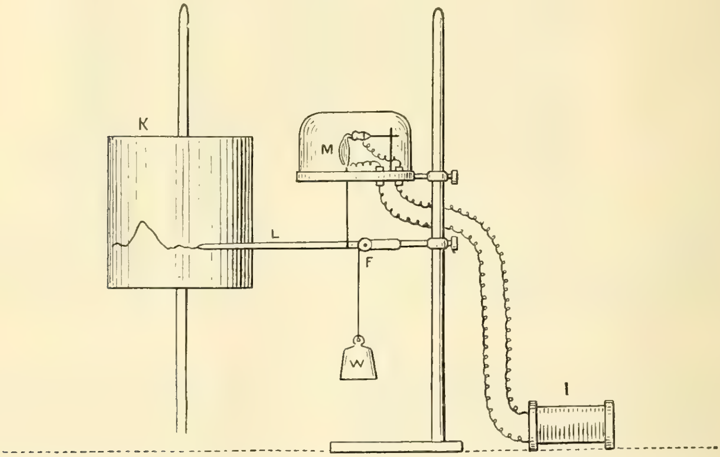

FIG. 25.—MYOGRAPH. K. Recording cylinder. M. Moist chamber. L. Recording lever. W. Weight. I. Induction coil.

action by a tuning-fork vibrating in hundredths of a second. In order to determine the rapidity with which the contraction follows the stimulation, it is essential that the movement of the latter be also recorded. This is accomplished by an automatic key, the opening or closing of which develops the stimulus which excites the muscle. A combination of these different appliances constitutes a *myograph* and the curve of contraction a *myogram.* (See Fig. 25.)

The Isotonic Myogram.—With the object of obtaining a curve of successive changes in the length of a muscle during a single contraction and at the same time avoiding changes in tension, the weight attached to the lever should be applied close to its axis, a mechanic condition which practically maintains a uniform tension throughout the contraction. To this method the term "isotonic" has been given and the curve so obtained an isotonic myogram.*

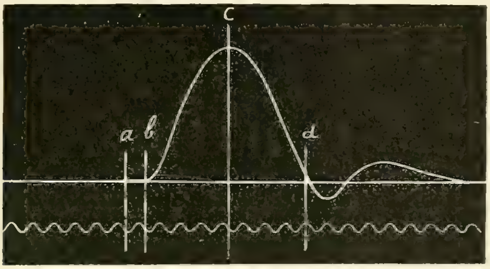

FIG. 26.—THE ISOTONIC MYOGRAM.

The Character of an Isotonic Myogram.—With the muscle arranged as previously described and stimulated directly with a single induction shock, the contraction will be recorded in the form of a curve similar to that represented in Fig. 26, in which the horizontal line represents the abscissa of time; a, the moment of stimulation; and b c d, the degree of shortening at each successive moment. The undulating line shows the time relations, the distance from crest to crest representing hundredths of a second. The curve may be divided into three portions:

1. A short but measurable portion between the point of stimulation and the first evidence of the shortening, a b, known as the "latent period." The duration of this period for the skeletal muscle of the frog was originally determined to be 0.01 second, but with the employment of more accurate apparatus it has been reduced to 0.0025 to 0.004 second. During this period it is supposed that certain chemic changes are taking place preparatory to the

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* In the ordinary method of recording a muscular movement, *i. e.*, with the weight attached to the lever immediately beneath the muscle and known as the "loaded method," a certain momentum is imparted to the weight, which continues after the muscle has ceased to act, both when shortening and relaxing, and so imparts to the recording lever additional movements which vitiate the true character of the curve.

exhibition of the movement. The duration of the latent period is influenced by a variety of conditions, *e. g.*, temperature, fatigue, strength of stimulus, etc.

2. An ascending portion, b c, the contraction or period of increasing energy. The contraction as shown by the character of the curve begins slowly, then proceeds rapidly, and again slowly as the shortening reaches its maximum. The contraction may be said to end when the tangent to the curve becomes parallel with the abscissa.
3. A descending portion, c d, the relaxation or period of decreasing energy. The relaxation as shown by the character of the curve begins slowly, then proceeds rapidly, and again slowly as the muscle attains its original length. The termination of the relaxation is at the point where the curve cuts the abscissa. The curve beyond this point may be complicated by the presence of one or more residual or after-vibrations, which are probably due to the inertia of the lever as well as to changes in the muscle elasticity.

The duration of the period of shortening is about 0.04 second, and of the period of relaxation 0.05 second. A single pulsation of the isolated muscle of the frog therefore occupies, from the moment of stimulation to termination, the tenth of a second. Muscles of many other animals have a contraction period the duration of which varies considerably from this. Thus, in man the time of a single contraction is one-twentieth of a second, in some insects one three-hundredth of a second, and in the turtle one second. Pale muscles have a shorter period than the red.

Influences Modifying the Contraction Process.—The contraction process in its entirety as well as in its individual parts is considerably modified by both external and internal conditions, among which may be mentioned the following:

1. *Stimulus.*—As the contraction is the response of the muscle to a stimulus, the vigor of the former is proportional, within limits, to the strength of the latter. Thus using as a stimulus the single induced current, it has been found that if the strength of the current is progressively increased, the height of the contraction will correspondingly increase until a certain maximum height is attained (Fig. 27, A); then notwithstanding a continued increase in the strength of the stimulus, this height will not be exceeded for some time. But if the strength of the stimulus be yet further increased, there comes a moment when the contractions again increase in vigor and a second maximum height is attained (Fig. 27, B). Beyond this no further increase in height is observed. The second maximum has been attributed to the presence in the muscle of two different substances differently affected by changes in temperature, by fatigue and by various drugs.

   The rate at which the muscle is stimulated with a given stimulus of uniform strength will also influence the character of the contraction process. If the intervals between the successive stimulations be such as permit the muscle to recover from the effects of the contraction, it may contract as many as a thousand times without showing any particular variation from the normal form; but if the intervals are shorter than that just stated it is found that from the beginning of the stimulation each succeeding contraction slightly exceeds in height the preceding contraction, until a certain maximum is reached and maintained, indicating that for some reason the irritability and the energy of the contraction have been increased. This gradual increase in the height of the contraction has been termed the stair case effect, or the *treppe.* In the beginning of the period of stimulation there is sometimes observed a decrease in the height of the contraction following several stimulations before the stair case effect develops, indicating a temporary decrease in the irritability. These stair case contractions have been observed in the muscle of both warm-blooded and cold-blooded animals. The cause for this increase in irritability upon which the effect depends is attributed to the presence of certain chemic substances in the muscle arising as a result of its katabolism, such as carbon dioxid, mono-potassium phosphate, and paralactic acid. These compounds when present in small amounts or in larger amounts for a short time, augment the action of the muscle and give rise to the treppe effect. (Lee.) In time, however, if the stimulation be continued, the irritability declines, the height of the contraction diminishes and finally the muscle ceases to respond to any stimulus.

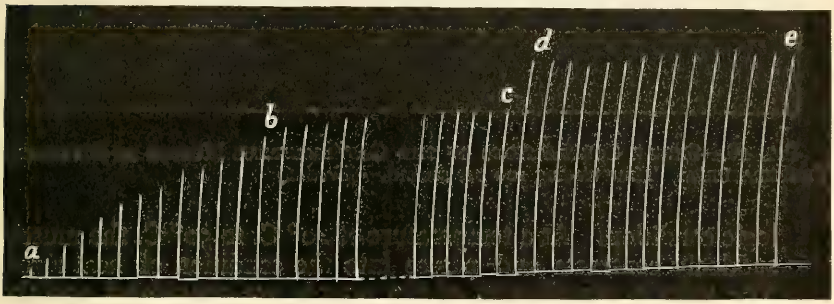

FIG. 27.—TRACING SHOWING THE EFFECTS OF A GRADUAL INCREASE IN THE STRENGTH OF THE STIMULUS ON THE HEIGHT OF THE CONTRACTION. *a.* Minimal contraction; *a b.* progressive increase in the height; *b c.* first maximum (a number of contractions have been omitted for economy of space); *d e.* second maximum.

2. *Temperature.*—The temperature at which all phases of the contraction process, as represented by the myogram, attain their physiologic maximum value is about 30° C. If the tempera-

ture of the muscle falls to 20° C. there is a corresponding decline in activity, as shown by an increase of the latent period, a decrease in the height of curve—*i. e.*, in the shortening of the muscle—an increase both in the contraction and relaxation periods. As the temperature approaches 0° C. the height of the curve again suddenly increases, indicating, for some unknown reason, an increase in the irritability. This is, however, scarcely a physiologic condition. At a temperature of 40° C. to 50° C. the muscle suddenly contracts and passes into the condition of heat rigor. The proteid constituents of the muscle are coagulated and the irritability destroyed. (Fig. 28.)

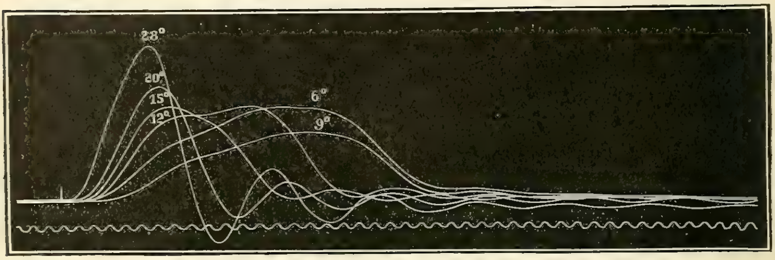

Fig. 28.—Single Contractions of the Gastrocnemius Muscle at Different Temperatures. Time tracing 200 per second.—(*Brodie.*)

The Load.—The extent to which a muscle is loaded or weighted will not only determine the height of the contraction, but also the time relations of all its phases. This is apparent from an examination of Fig. 29, in which it is shown that with an increase in load there is a decrease in the height of the contraction, an increase in the latent period, and a general increase in the duration of both the periods of rising and falling energy.

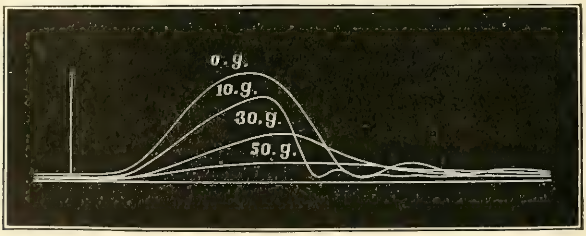

Fig. 29.—Contractions of a Gastrocnemius Muscle with Different Loads.—(*Brodie.*)

4. *Continuous Stimulation.*—Prolonged or excessive activity of our own muscles is accompanied by a feeling of stiffness or soreness and lassitude. There is at the same time a diminution in the speed

and vigor of the contractions and the power of doing work. To this condition the term fatigue has been given. The cause of the fatigue is attributed to a diminution in the amount of the energy-yielding compounds as well as to the production and accumulation of waste products resulting from katabolic activity. Among the waste products mono-potassium phosphate, paralactic acid, and carbon dioxid are the most important. These substances, when present in small amounts or in larger amounts for a short time, increase the irritability of the muscle, but when they accumulate more rapidly than they are removed, as is the case during excessive activity, they exert a depressive influence on the irritability of the muscle and thus diminish its contractile power and its capacity for doing work. The more rapidly they are removed, the sooner is a fatigued muscle restored to its normal condition. The condition of fatigue with its attendant phenomena is shown by stimulating through its nerve an excised frog muscle with induced electric currents at intervals of one second. In a variable period of time the muscle shows an increase in the duration of the latent period, a diminution of the height of the contraction, in the power of doing work, and an increase in the time required for relaxation. (Fig. 30.) If the stimulation is continued the contractions gradually decline as the muscle becomes exhausted. When a muscle will no longer respond to stimulation through its related nerve, it can be made to respond to direct stimulation with the electric current. This taken in connection with the fact that stimulation of a nerve-trunk even for several hours does not fatigue it, leads to the inference that the cause of the cessation of contraction does not wholly lie in the muscle but partly in the nerve endings in the muscle. These structures it is believed fatigue more readily than the muscle structures, and hence fail to conduct the nerve impulse to the muscle. By this means it is protected from absolute exhaustion.

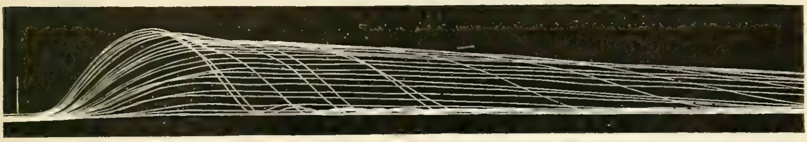

Fig. 30.—Fatigue Curves. Every Twentieth Contraction Recorded.

5. *Nutrition.*—The irritability of a muscle which conditions the contraction process is dependent on the maintenance of its nutrition; hence a continuous and sufficient supply of nutritive material and a rapid removal of waste products are essential conditions for the exhibition of normal contractions. A diminution of blood supply or an accumulation of waste products sooner or later impairs the irritability and diminishes the vigor and extent of the

contraction. Various drugs—*e. g.*, veratrin, barium, etc.—introduced into the circulation and finding their way into the muscle modify the contraction process, as shown by a very great increase in the duration of the relaxation period.

The Isometric Myogram.—With the object of obtaining a curve of the increase and decrease in the tension of a muscle during a single contraction, with the exclusion as far as possible of a change in length, the muscle may be made to contract against a strong spring or similar resistance sufficient to practically though not absolutely prevent shortening. To this method the term isometric has been given, and the curve so obtained an *isometric myogram* or a *tonogram*. The recording portion of the lever is prolonged some distance so that the very slight upward movement at its axis, close to which the muscle is attached, will be considerably magnified. That the ordinate value of an isometric curve may be known, the apparatus must be graduated by subjecting the spring to a series of weights playing over a pulley supported by the muscle clamp.

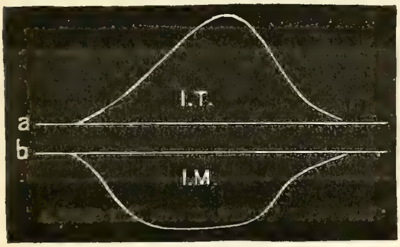

Fig. 31.—a. Diagram of Isotonic; b, of Isometric Muscle Curves.—(*Landois and Stirling.*)

The curve of the variation in tension obtained by the isometric method is shown in Fig. 31, b, in which the two curves are contrasted. The form of the curve indicates that the muscle attains its maximum of tension more rapidly than its maximum of shortening; that the tension endures for a certain period of time unchanged; that the fall in tension takes place more rapidly than the muscle relaxes.

The Myogram Due to the Make and the Break of a Galvanic Current.—The contraction of the muscle which has heretofore been recorded has been caused by the momentary action of an induced current. The contraction of the muscle which is caused by the action of a constant or galvanic current presents features which are somewhat different and as it serves to illustrate the difference in the effects of a constant or galvanic and an induced or interrupted current, a myogram of a contraction due to the make and break of a galvanic current is introduced at this place. The effects which are observed in a muscle during the passage of both feeble and strong currents have been alluded to in a previous section. (See page 61.) In Figure 32 these effects are graphically represented. It will be observed that on the closure of the circuit at c the muscle at once contracted and so long as the current was flowing, the muscle remained in a more or less contracted state known as galvanotonus; on opening the circuit at o the muscle again contracted, after which it gradually relaxed and returned to its original condition. The record shows also that during the actual passage of the current the muscle substance was being stimulated by it.

The Work Accomplished by a Muscle during the Time of a Single Contraction.—By work is meant the overcoming of opposing forces. In the physiologic activities of the body the muscles at each contraction not only overcome the resistances of antagonistic muscles, the weight of the limbs, the friction of joints, etc., but in addition overcome various external resistances connected with the environment—*e. g.*, gravity, cohesion, friction, elasticity, etc. The muscles may therefore be regarded as machines for the accomplishment of work. Experimentally the work done by an isolated muscle may be calculated when first the height of the contraction is obtained and then multiplying it by the weight raised. The influence of the weight on the height of the contraction is shown in Fig. 33. From this tracing it will be observed that the extent to which a muscle will shorten in response to a maximal stimulus is greatest when it is unweighted; but as weights differing by a common increment are added, the height of the contraction diminishes until with a given weight it is *nil.*

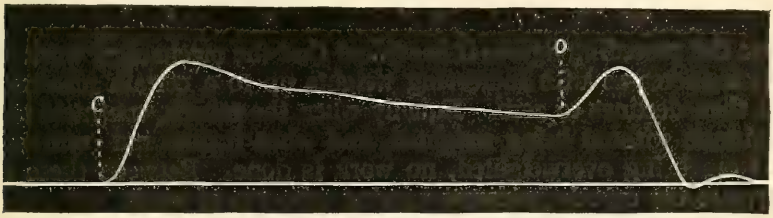

Fig. 32.—A Myogram Due to the Action of a Galvanic Current, Applied Directly to a Muscle, when the Circuit was Closed (*c*) and when it was Opened (*o*).

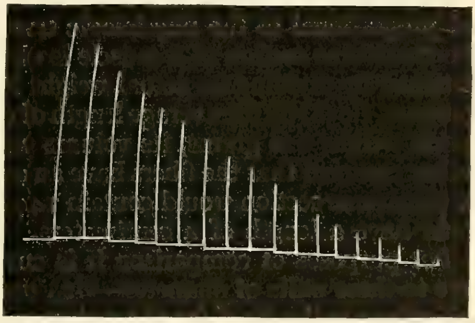

Fig. 33.—Tracing Showing the Gradual Diminution in the Height of the Contraction as the Weight was Increased by a Common Increment of 10 Grams from 0 to 180 Grams. Magnification of the Lever, 4.

A careful study of the results of this experiment will show that the work done gradually increased as the load was increased from 0 to 70 grams, when it amounted to 210 milligrammeters; but that after this, even though the weight lifted was greater, the height to which it was lifted was less, and hence the work done gradually decreased, until it amounted to nothing.

The following table will also show the work done by a frog's muscle according to Rosenthal.

WEIGHT.	HEIGHT.	WORK DONE.
0 grams	14 mm.	0 gram-millimeters
50 "	9 "	450 "
100 "	7 "	700 "
150 "	5 "	750 "
200 "	2 "	400 "
250 "	0 "	0 "

From the preceding figures it is evident that the mechanical work of a muscle increases with increasing weights up to a certain maximum, and then declines to zero. Equally when the muscle contracts to its maximum without being weighted, and when it does not contract at all from being overweighted, no work is done. Between these two extremes the muscle performs varying amounts of work.

The maximum amount of force which a muscle puts forth during a contraction is naturally measured by the amount of work done; but as this varies with the degree to which the muscle is weighted, another measure has been adopted, to which the term absolute muscle force or static force has been given. The absolute force is measured by the weight which is sufficient to prevent the muscle from shortening. This is best determined by the method of after-loading in which the muscle is not extended by the weight previous to the contraction. It has been found that the absolute force of a muscle is directly dependent on the number and not the length of the fibers it contains and proportional to the physiologic transverse section of the muscle. The transverse section of a muscle is obtained by dividing its volume (obtained by dividing its actual weight by the specific weight of muscle-tissue, 1.058) by the average length of the fibers. Assuming that the muscle weighs 622 grams, its volume would be 576 c.c.; and if it be further assumed that the fibers have an average length of 4 centimeters the transverse section would contain 144 sq. centimeters each of which would have a length of 4 centimeters.

For purposes of comparison it is customary to refer the absolute force to these units of diameter—viz., one square centimeter. Rosenthal estimates the force for the square centimeter of the muscle of the frog at from 2 to 8 kilograms; for the muscles of man at 6 to 8 kilograms; Koster at about 10 kilograms for the muscles of the leg and 7 or 8 kilograms for the muscles of the arm.

Summation Effects.—If a series of successive stimuli be applied to a muscle, the effect will vary according to the rapidity with which they follow one another. As previously stated, if the interval preceding each stimulus be sufficiently long to enable the muscle to recover from the effects of the previous contraction, there will be no change in the form or the character of the contraction for a long time except a slight increase, in the early period, of the irritability as shown by the increased height of the curve or shortening of the muscle. If, however, a second stimulus be applied to a muscle during the period of relaxation, a second contraction immediately follows which is added to or superposed on the first; the effect produced will be greater than that produced by either stimulus separately. See Fig. 34.

A third stimulus applied during the relaxation of the second contraction produces a third contraction which adds itself to the second, and so on. The increment of increase in the extent of the successive contractions gradually diminishes, however, until the muscle reaches a maximum of contraction. The superposition of the second contraction on the first, the third on the second, and so on, is termed *summation of contractions or effects*. Experiment has shown that the greatest effect of a second stimulus—that is, the highest contraction—is produced when the stimulus is applied during the last third of the period of rising energy, when the sum of the two contractions is almost twice as great as the first contraction (Fig. 34). The effects following both maximal and submaximal stimuli indicate that the muscle cannot attain its maximum of shortening except through a summation of several stimuli. If a second maximal stimulus enter a muscle during the latent period following the first, the effect produced will be no greater than that produced by a single stimulus. The muscle during this period is said to be refractory or non-responsive to a second stimulus. If, however, the stimuli are submaximal they add themselves together, and though the effect is but a single contraction, it is larger than either would have produced separately. This is termed the *summation of stimuli*.

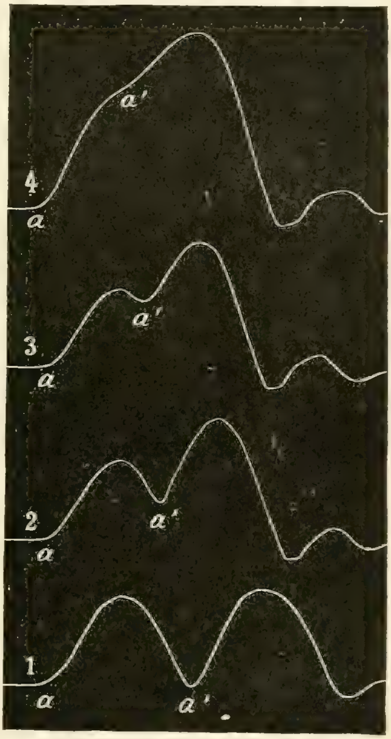

Fig. 34.—Tracing Showing the Effects of Two Successive Stimuli, *a. a'* with Gradually Diminishing Interval on a Muscle Contraction. To be read from below upward.

Still further, if a series of subminimal stimuli, each of which is alone insufficient to produce a contraction of the muscle, be applied in rapid succession, a contraction frequently results. This is termed the *summation of subminimal stimuli*.

Tetanus.—Tetanus may be defined as a more or less continuous contraction of a muscle which arises when the time intervals between the stimuli are shorter than the time of the contraction process. Tetanus will be incomplete or complete according to the number of stimuli that fall into the muscle in a second of time. When a muscle is stimulated directly or, better, indirectly through its related nerve by a series of induced currents at the rate of four or six per second, it undergoes a corresponding number of contractions of about equal extent. If the rate of stimulation is increased up to the point when the interval between each stimulus is less than the duration of the entire contraction process, the muscle does not have time to completely relax before the arrival of the succeeding stimulus, and hence remains in a more or less contracted state, during which it exhibits a series of alternate partial contractions and relaxations. To this condition of muscle activity the term incomplete tetanus or clonus is applied. A graphic record of an incomplete tetanus is given in Fig. 35.

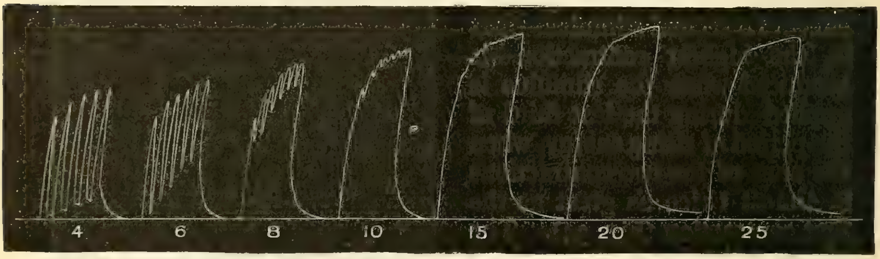

FIG. 35.—CURVES SHOWING THE ANALYSIS OF TETANUS OF A FROG'S MUSCLE (GASTROCNEMIUS). The numbers under the curves indicate the number of shocks per second applied to the muscle. There is almost complete tetanus with twenty-five per second, and it is a little lower than the previous one because the muscle was slightly fatigued.—(*Stirling.*)

In such a tracing it is observed that the second stimulation, occurring before the muscle had time to relax, gave rise to a second contraction, which was superposed on the first; the same result followed the third stimulus, the fourth, the fifth, and so on. Owing largely to this summation of the contractions there is a gradual rise in the height of the contraction curve. This condition of the muscle, viz., continued contraction, combined with diminished power of relaxation, is termed *contracture*. The tracing also shows that as the stimulus continues, the base line, that connecting the lowest points of the contractions, gradually rises and takes the form of a curve which increases in height with the stimulation. The apex line, that connecting the highest points of the contractions, also rises at the same time, indicating a continuous increase in the height of the contractions. The length of time a muscle will exhibit incomplete tetanus depends on a variety of circumstances, *e. g.*, character of muscle, rate and strength of stimulation, etc., but mainly on the rapidity with which the muscle becomes fatigued. With the oncoming of fatigue the muscle begins to relax, and ultimately returns to its normal condition, notwithstanding the continued stimulation. If the stimulation be withdrawn, the muscle does not at once return to its original length but remains more or less contracted for a variable time. This contraction after stimulation is known as the contraction-remainder.

If the stimulation be still further increased in frequency, the individual contractions become fused together and the curve described by the lever becomes a continuous line. (See Fig. 35.) Notwithstanding the fact that the individual contractions are no longer visible, it can be shown by other methods that the muscle is undergoing a series of slight alternate contractions and relaxations or vibrations at least. After a varying length of time the muscle becomes fatigued, relaxes, and returns to its natural condition even though the stimulation be continued. The number of stimuli per second necessary to develop complete tetanus will depend under normal circumstances on the period of duration of the individual contractions. The longer this period, the less the number of stimuli required, and the reverse. Hence the number of stimuli will vary for different classes of animals and for different muscles in the same animal, *e. g.*, 2 or 3 for the muscles of the tortoise, 10 for the muscles of the rabbit, 15 to 20 for the frog, 70 to 80 for birds, 330 to 340 for insects.

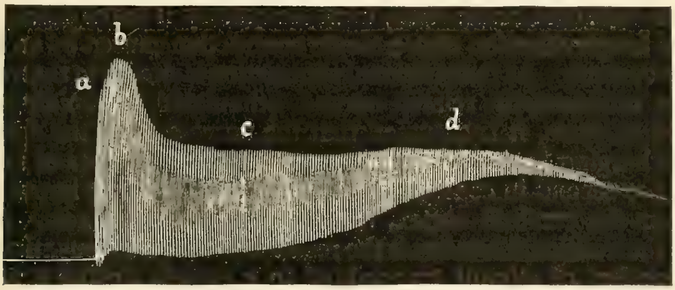

FIG. 36.—DEVELOPMENT OF FATIGUE AND CONTRACTION. Muscle stimulated once a second by a strong induced current.

An effect which follows frequent stimulation of a muscle, *e. g.*, 50 to 60 times per minute, and especially when the muscle is somewhat fatigued or cold is shown in Fig. 36. It is evidently a combination of contracture and fatigue. It will be observed that at the beginning of the stimulation there is a stair case effect, a–b, combined with diminished relaxation. This in turn is followed by a decline in the height of the contractions, b–c, and a fall of the base line which may be attributed to fatigue conditions. After a short time there is a second rise of the base line, d, and a rapid development of contracture. The muscle at this period is in a condition of incomplete tetanus which gradually passes into complete tetanus attended by fatigue.

The tetani of muscles may be classified in accordance with their causes as follows:—

1. Physiologic
    - Volitional.
    - Reflex.
2. Experimental.
3. Pharmacologic.
4. Pathologic
    - Bacterial.
    - Reflex.

1. Physiologic Tetanus.—1. *Volitional.*—Because of the fact that during the continuance of a volitional movement the muscle is in a state of continuous contraction, it may be accepted that volitional contractions are states of tetanus, more or less complete; for the shortest possible volitional contraction, however quickly it takes place, has always a longer duration than a single contraction caused by an induced electric current. As the volitional contraction is similar to that observed when a muscle or its related nerve is stimulated by rapidly repeated induced currents, it is assumed that the nerve-cells in the spinal cord are discharging in a rhythmic manner a certain number of nerve impulses per second in consequence of the arrival of nerve impulses coming from the cerebral cortex, the result of volitional acts. In other words the volitional tetanus is the result of a discontinuous stimulation. The number of stimuli transmitted to a muscle during a volitional tetanus has been estimated by the employment of the graphic method at from 8 to 13 per second, 10 being about the average. When a volitional contraction is recorded the myogram not infrequently exhibits a series of small wave-like elevations which indicate that the muscle is not in a state of complete tetanus but is undergoing slight alternate contractions and relaxations. Unless the contraction process in human muscle differs from that of frogs it is difficult to see how 10 or even 20 stimuli per second can give rise to even an incomplete tetanus when the single contraction is $\frac{1}{20}$ of a second in duration.

2. *Reflex.*—A tetanus of muscle, physiologic in character, arises during the performance of many muscle movements in consequence of peripherally acting causes and may therefore be termed a reflex tetanus. The duration of a tetanus thus induced, like the duration of a volitional tetanus, will vary with the duration of the exciting cause. Reflex tetani are presented by the muscles of the lower jaw during mastication, by the intercostal muscles during breathing, by the muscles of the limbs during walking, etc. In these and other instances there are reasons for believing that for a variable period of time the muscles are in a state of continuous contraction from the discharge of nerve impulses from the nerve cells in the spinal cord as the result of the arrival of nerve impulses coming from a peripheral surface.

2. **Experimental Tetanus.**—The tetanus of muscle developed in accordance with the method described in foregoing paragraphs, *i. e.*, by the employment of instrumental procedures, may be termed experimental tetanus. Its mode of development serves to illustrate and explain the method by which individual contractions are summated and continuous contractions made possible for the performance of volitional acts.

3. **Pharmacologic Tetanus.**—The administration of certain drugs, *e. g.*, strychnin, in sufficient amounts, is followed in a short time by a series of intermittent spasms in which all the muscles of the body are involved. At the beginning of the spasms the muscles are thrown into tonic or complete tetanus, during the continuance of which the muscles are hard and firm. In a short time this tonic state begins to subside, giving way to tremors or a series of irregular contractions resembling incomplete tetanus or clonus. A tetanus of this character may be termed pharmacologic. Though the onset of the tetanus is occasioned largely by peripheral stimulation, the seat of action of strychnin is central and for the most part focalized in the spinal cord. The exact seat of its action is not definitely determined but there are reasons for believing that it is on the end-tufts of afferent nerves in the spinal cord or on the intercalated neuron between them and the nerve-cells in the anterior horns of the gray matter, the irritability of which is raised and the resistance to the transmission of nerve impulses coming from the periphery diminished. As a result the nerve impulses are transmitted to the nerve-cells more readily, not only in a horizontal but also in a longitudinal direction, and the effects they produce enormously increased.

4. **Pathologic Tetanus.**—1. *Bacterial.*—The introduction of a specific bacillus into a wound in any region of the body is followed after a period of incubation of from three or four days to a week by a tetanus in which nearly all the muscles of the body are involved, characterized by a tonic contraction and clonic exacerbations. A tetanus of this character may be termed pathologic. The persistent tonic contraction is the result of a more or less continuous discharge of nerve impulses from the nerve-cells of the spinal cord which have been rendered abnormally irritable by the action of a toxin, produced by the bacilli, and which has a selective action on these structures. The clonic exacerbations are evoked from time to time by various forms of peripheral stimulation.

2. *Reflex*—A tetanus of individual muscles more or less continuous in character is occasionally the result of peripheral irritations of a pathologic character. A tonic contraction of the masseter muscles, for example, firmly closing the jaws for weeks and months at a time is caused in some instances by an impacted wisdom tooth or an ulcerative condition of the mouth. Since the removal of the cause is followed by a relaxation of the muscle, this form of tetanus, known as *trismus*, may be regarded as pathologic in character and reflex in origin.

The Muscle Sound.—If a stethoscope or a myophone with telephone connections be placed on a muscle while in a condition of volitional tetanus and at the same time kept in a certain degree of tension, there will be developed in the observer a sensation of sound or tone which is spoken of as a muscle sound or tone. It is also readily heard in the masseter muscle when the side of the face is placed on a receiving body such as a pillow, and the masseter muscles made to contract volitionally. This tone is attributed to a vibration or an alternate contraction or relaxation of the muscle or to an intermittent rhythmic variation in tension, the result of the rate of stimulation. This tone corresponds to a vibration frequency of from 18 to 20 per second and is accepted as one of the proofs that the physiologic volitional tetanus is not continuous but discontinuous in character. If a muscle is tetanized with induced currents, the tone increases in pitch for a limited time as the frequency of the current per second increases up to a certain maximum, which for frogs is about 200 and for mammals about 1000.

CHEMIC PHENOMENA.

The chemic changes which underlie the transformation of energy in the living muscle even when in a state of rest are active and complex, though but little is known as to their exact character. As shown by an analysis of the blood flowing to and from the resting muscle, it has, while flowing through the capillaries, lost oxygen and gained carbon dioxid. The amount of oxygen absorbed by the muscle (9 per cent.) is greater than the amount of carbon dioxid (6.7 per cent.) given off. Notwithstanding the relation of the oxygen absorbed to the carbon dioxid produced, there is no parallelism between these two processes, as the carbon dioxid will be given off in the absence of free oxygen or in an atmosphere of nitrogen.

In the active or contracting muscle all the chemic changes are increased, as shown both by an increased absorption of oxygen and an increased production of carbon dioxid, though the ratio existing between them differs considerably from that of the resting muscle. Thus, according to Ludwig, an active muscle absorbs 12.26 per cent. of oxygen and gives off 10.8 per cent. carbon dioxid. During the activity of a muscle its tissue changes from a neutral to an acid reaction, from the development of sarcolactic acid and possibly phosphoric acid. The degree of the acidity depends to some extent on the duration of the contraction periods. Chemic analysis of a tetanized muscle shows that it contains less glycogen than a resting muscle, and that it contains a larger amount of water. Coincident with muscular contraction, the blood-vessels become widely dilated, leading to a large increase in the blood-supply and a rapid removal of the products of decomposition.

Rigor Mortis.—A short time after death the muscles pass into a condition of extreme rigidity or contraction known as death stiffening or *rigor mortis*, which lasts from one to five days. In this state they offer great resistance to extension. At the same time their tonicity disappears, their cohesion diminishes, and their irritability ceases. The time of the appearance of this post-mortem rigidity varies from a quarter of an hour to seven hours. Its onset and duration are influenced by the condition of the muscle irritability at the time of death. When the irritability is impaired from any cause, such as chronic disease or defective blood-supply, the rigidity appears promptly but is of short duration. After death from acute diseases it is apt to be delayed, but will continue for a longer period. The rigidity first appears in the muscles of the lower jaw and neck; next in the muscles of the abdomen and upper extremities; finally in the trunk and lower extremities. It disappears in practically the same order. Chemic changes of a marked character accompany this process. The muscle becomes acid in reaction from the development of sarcolactic acid and there is a large increase in the amount of carbon dioxid given off. The immediate cause of the rigidity appears to be coagulation of the myosinogen within the sarcolemma with the formation of an insoluble protein, myosin. In the early stages of the coagulation restitution is possible by the circulation of arterial blood through the vessels. The final disappearance of this post-mortem rigidity is due probably to the action of acids which render the myosin soluble, and possibly to the action of various microörganisms which give rise to putrefactive changes.

Source of the Muscle Energy.—Notwithstanding many investigations, the nature of the materials which are the immediate source of the muscle energy is not known. The absence of any noticeable increase in the quantity of urea or other nitrogen-holding compounds excreted renders it probable that the energy does not come from the metabolism of proteid materials. The marked production of carbon dioxid and sarcolactic acid points to the decomposition of some unstable compound, of a carbohydrate character, rich in carbon and oxygen. It has been suggested that glycogen furnishes the energy, inasmuch as this substance, generally present in muscle, disappears during activity. A muscle which has been tetanized contains less glycogen than the corresponding muscle at rest. A muscle which has been separated from the nervous system by division of its nerves and thus prevented from contracting accumulates glycogen. Bunge is of the opinion that though the carbohydrates are the main, they are not the only sources of muscle energy. If there is a deficiency or absence of carbohydrate food, the muscle will utilize fat and proteid, for experiment has shown that the available glycogen is entirely consumed the second or third day. The mechanism by which the energy is liberated, whether by decomposition or direct oxidation, is unknown. The fact that muscle will contract in an atmosphere free of oxygen, that no free oxygen can be obtained from muscle, would support the idea that the mechanism is one of decomposition. Hermann suggests that the energy of a contraction is liberated by the splitting and subsequent re-formation of a complex body belonging neither to the carbohydrates nor fats, but to the proteids—to this hypothetic body the term inogen is given. This complex molecule, the product of the nutritive activity of the muscle-cell in undergoing decomposition, would yield carbon dioxid, sarcolactic acid, and a proteid residue resembling myosin. On the cessation of the contraction the muscle-cell recombines the proteid residue with oxygen, carbohydrates, and fats, and again forms the energy-holding compound, inogen. The phenomena of rigor mortis support this view. At the moment of this contraction the muscle gives off CO_2 in large amount, develops sarcolactic acid and myosin. There is thus a close analogy between the two processes; in other words, a contraction is a partial death of the muscle. If this view is correct, then the oxygen is required mainly for heat production through oxidation processes.

THERMIC PHENOMENA.

The potential energy liberated during a contraction is transformed into kinetic energy—viz., heat and mechanic motion. Though heat production is taking place even during the passive condition, probably through oxidation processes, it is largely increased by muscle activity. The skeletal muscle of the frog, the gastrocnemius, shows after tetanization an increase in temperature from 0.14° C. to 0.18° C., and after a single contraction from 0.001° C. to 0.005° C. The amount of heat thus produced will vary with a variety of conditions, as strength of stimulus, tension, work done, etc.

Stimulus.—It has been experimentally determined that an increase in the strength of the stimulus from a minimal to a maximal value increases the amount of heat liberated. This is the direct result of increased chemic change naturally following increased stimulation.

Tension.—The greater the tension of a muscle, the greater, other conditions being the same, is the amount of heat liberated. If the muscle is securely fastened at both extremities so that shortening is practically impossible during the stimulation, the maximum of heat production is reached. In the tetanic state the great increase in temperature is due to the tension of antagonistic and strongly contracted muscles. In both instances, mechanic motion being prevented, the liberated energy is transformed into heat.

Mechanic Work.—If the muscle is permitted to shorten and raise a weight, some of the energy liberated takes the form of mechanic motion. If the weight is removed at the height of the contraction, external work is accomplished. The greater the weight raised, within limits, the greater is the percentage of energy which takes the direction of mechanic motion. The percentage of the total energy liberated which is thus utilized, has been estimated at from 25 to 40 per cent. In accordance with the law of the conservation of energy, the heat produced, stated in calories, plus the energy required in the raising of the weight, expressed in kilogrammeters of work, must equal the potential energy transformed.

A muscle during a tetanic contraction of short duration accomplishes more work than during a single contraction; the weight in each case being the same. In the former condition the height of contraction through summation, and hence the work done, is greater than in the latter. The work done by a short tetanic contraction may be two or three times that of a single contraction, but after the muscle reaches its maximum degree of shortening and then continues in a state of tetanus, no further work is done. Internal work is done, however, as shown by an increase in the temperature.

When a weight which is lifted by a muscle during a single contraction is allowed to act on the muscle during the relaxation, no external work is accomplished. All the energy set free manifests itself as heat. Internal work is done, as shown by the fact that the muscle becomes fatigued.

Work Done Daily.—The muscle system in its entirety is to be regarded as a machine for the transformation of potential into kinetic energy, and in so doing accomplishes work. Through the intermediations of the bones of the sketelon which play the part of levers the individual not only changes his position in space, but overcomes to some extent the resistances offered by the environment. The employment of artificial levers, tools, as distinguished from natural levers, bones, materially adds to the effectiveness of the muscle machine. The amount of work which a man of average physical development weighing 72 kilos can perform in eight hours has been variously estimated. It will naturally vary according to the character of the occupation. If the work done be calculated from the number of kilograms raised one meter, the average laboring-man performs about 300,000 kilogrammeters.

ELECTRIC PHENOMENA.

Electric Currents from Injured Muscles.—The energy liberated during a muscle contraction is not only transformed into heat and mechanic motion, but to some extent also into electric energy. The presence of points of different potential on the surface of the muscle, the necessary condition for the development of electric currents, is tested by means of non-polarizable electrodes connected by wires with a sensitive galvanometer or capillary electrometer. When such electrodes are brought in contact with a muscle properly prepared, there is at once developed and conducted to the galvanometer an electric current the intensity and direction of which are indicated by the deflection of the galvanometer needle. The existence of this current is most conveniently demonstrated with single muscles the fibers of which are parallel—*e. g.*, the sartorius, or the semimembranosus of the frog. If the tendinous ends of either of these muscles be removed by a section made at right angles to the long axis, a muscle prism is obtained which presents a natural longitudinal surface and two artificial transverse surfaces. A line drawn around the surface of such a muscle prism at a point midway between the two transverse sections constitutes the equator.

When the natural longitudinal and artificial transverse surfaces are connected with the wires of a galvanometer the terminals of which are provided with non-polarizable electrodes, an electric current is at once developed. In all instances the current, as shown by the deflection of the needle, originates at the transverse surface, passes through the muscle to the longitudinal surface, thence through the galvanometer to the transverse surface. The longitudinal surface is, therefore, electropositive, the transverse surface electronegative. The two points exhibiting the greatest difference of potential, and hence the most powerful current, lie in the equator and in the center of the transverse surface. Currents of gradually diminishing intensity are obtained when the electrode placed on the longitudinal surface is removed toward either end. Feeble currents are developed when two points situated at unequal distances, either on corresponding or opposite sides of the equator, are connected; in either case the current flows from the point lying nearest the equator to the point farthest from it. Similar currents are obtained when two points on the cross-section situated at unequal distances from the central axis are connected, in which case the direction of the currents will be from the point lying nearest the periphery toward the center. On the contrary, no current is developed when two points on the longitudinal surface equally distant from the equator, or two points on the transverse surface equally distant from the central axis, are connected. Such points are said to be isoelectric. These facts are shown in Fig. 37. The natural ends of the muscle, enclosed by sarcolemma and tendon, do not exhibit, if carefully preserved from injury, the negativity characteristic of the artificial transverse ends.

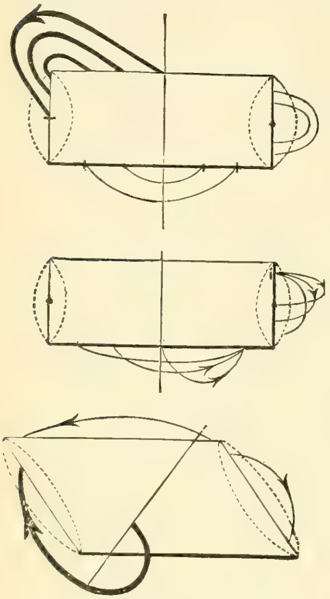

FIG. 37.—DIAGRAM TO ILLUSTRATE THE CURRENT IN MUSCLE. The arrowheads indicate the direction; the thickness of the lines indicates the strength of the currents. —(*Landois and Stirling.*)

Similar electric conditions are exhibited by the muscles of man and other mammals, by the muscles of birds, reptiles, amphibia, etc. The currents developed by connecting the equator on the longitudinal surface with the axis of the transverse surface have an electromotive force in the frog muscle of from 0.037 to 0.075 of a Daniell cell.

The electric currents in the muscle are intimately associated with the chemic changes underlying its nutrition, and hence their intensity rises and falls with all the conditions which maintain or impair muscle nutrition and irritability. The currents observed in the injured muscle during the inactive state have been termed *currents of rest.* du Bois-Reymond regarded them as pre-existent, intimately connected with the living condition of the muscle, and essential to the performance of its functions, and to be explained by the view that the entire muscle is composed of molecules each of which exhibits the same difference of potential on its longitudinal and transverse surfaces as the muscle prism itself. Hermann denies the existence of currents in normal resting muscle and attributes them to injuries of the surface, due to methods of preparation, in consequence of which the tissue dies and becomes electronegative to the uninjured area, which remains electropositive. These currents Hermann terms "demarcation currents."

Negative Variation of the Muscle Current.—If a muscle exhibiting a current of injury be excited to activity by tetanizing induced currents applied to the opposite end of the muscle, it will be observed that as the contraction wave passes over the muscle there is a movement of the galvanometer needle toward the zero point, indicating a diminution of the potential on the longitudinal surface. To this diminution in the strength of the current the term *negative variation* was given. On the withdrawal of the stimulus the needle again returns in a short time to its former position. The diminution of potential on the longitudinal surface of the muscle is now attributed to the passage of the excitation and contraction processes, to a temporary disintegration of the muscle substance (Fig. 38). With their disappearance and the subsequent restoration of the nutrition of the muscle, the former electric condition returns.

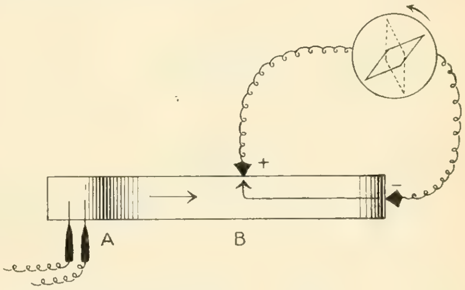

Fig. 38.—The Negative Variation of the Demarcation Current. A. The contraction wave, which as it passes beneath the electrode at B causes a diminution of potential.

The primary deflection of the galvanometer needle is due to the demarcation current which arises as a result of the difference in electric potential produced by the destructive chemic changes taking place at the cut end of the muscle. The negative variation is caused by the fact that the activity of the muscle, with its attendant chemic changes, will always be greater in the uninjured equatorial region, and hence will always tend to counterbalance the original source of difference in electric potential.

Electric Currents from Non-injured Muscles.—Though perfectly normal resting muscle, according to Hermann, is isoelectric, nevertheless electric currents are developed during activity to which he has given the term action currents, and which are attributed to the propagation of the contraction wave.

Action Currents.—When two isoelectric points on the longitudinal surface of a muscle are connected with a galvanometer and a single stimulus applied directly to one extremity, it can be shown that as the contraction wave passes beneath A, Fig. 39, the muscle-tissue at that point becomes electronegative toward B and a current at once passes through the galvanometer from B to A, as shown by the deflection of the needle toward A. As the contraction wave passes beneath B it in turn becomes electronegative, and a temporary condition of equal potential is established when the needle returns to the zero point. In a very short time the nutrition of A is restored and becomes electropositive toward B, when a current will pass through the galvanometer in the opposite direction from A to B, as shown by the movement of the needle toward B, Fig. 40. As the contraction wave passes beyond B its nutrition is restored and becomes of equal potential with A. The term phasic is applied to these currents. The first current flows in the muscle in the direction of progress of the contraction wave—first phase; the second current flows in the reverse direction—second phase; the current is therefore diphasic. When a muscle is tetanized, there is but a single current observed, which, however, endures so long as the tetanic contraction is maintained. To this current the term decremential is given. When a muscle is excited to action by the nerve impulse which enters at its center, two contraction waves are developed, one in each half of the muscle, and hence there are two sets of diphasic action currents.

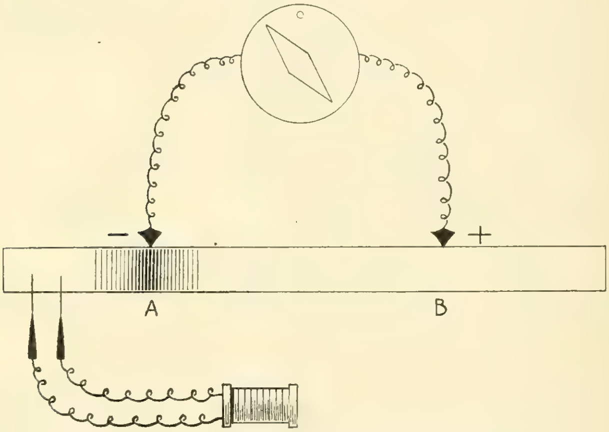

FIG. 39.—THE CONDITION LEADING TO THE DEVELOPMENT OF THE FIRST ACTION CURRENT.

The presence of action currents in the muscle of the living body during a single contraction was demonstrated by Hermann in the muscles of the forearm. The arrangement of the experiment was, briefly, as follows: The forearm was surrounded by two twine electrodes saturated with zinc solution, one being placed at the physiologic middle—the nervous equator—the other at the wrist. Both electrodes were then connected with the galvanometer. When the brachial plexus was stimulated in the axillary space, the deflections of the galvanometer needle, when analyzed with the repeating rheotome, indicated phasic currents with a single contraction. In the first phase—atterminal—the wrist became positive and the current passed in the muscle toward its termination; and in the second—abterminal—it became negative and the current now passed in the reverse direction. The action currents which are observed in the frog's muscle were thus shown to be present in the living human muscle, with this difference, however: that the second phase—abterminal—instead of being weaker in man, is equally strong with the atterminal. This experiment also revealed the fact that the rapidity of propagation of the excitation wave was much greater in man, amounting to about twelve meters per second. Hermann therefore denies the pre-existence of electric currents and regards them as due to localized temporary disintegration of the muscle in consequence of activity, as they disappear on the restoration of the muscle to its normal condition.

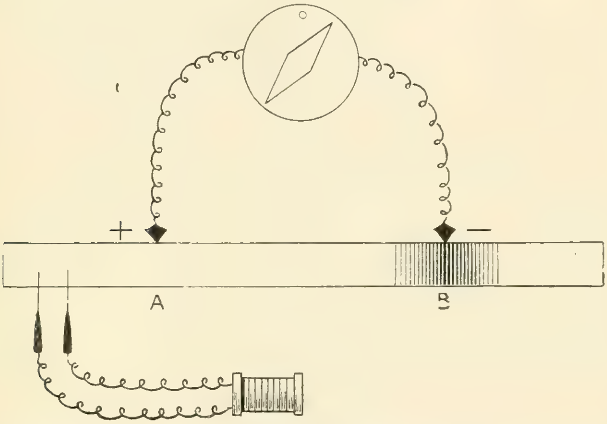

Fig. 40.—The Condition Leading to the Development of the Second Action Current.

SPECIAL ACTION OF MUSCLE GROUPS.

The individual muscles of the axial and appendicular portions of the body are named with reference to their shape, action, structure, etc.; *e. g.*, deltoid, flexor, penniform, etc. In different localities a group of muscles having a common function is named in accordance with the kind of motion it produces or to which it gives rise: *e. g.*, groups of muscles which alternately diminish or increase the angular distance between two bones are known respectively as flexors and extensors; such muscle groups are usually found in association with ginglymus joints. Muscles which rotate the bone to which they are attached around its own axis without producing any great change of position are known as rotators, and are found in association with enarthrodial or ball-and-socket joints. Muscles which impart an angular movement to the extremities to and from the median line of the body are termed adductors and abductors respectively.

In addition to the actions of individual groups of muscles in producing special movements, in some regions of the body, several groups of muscles are coördinated for the accomplishment of certain definite functions; *e. g.*, the functions of respiration, mastication, etc. The coördination of axial and appendicular muscles enables the individual to assume certain postures, such as standing, sitting, and lying; to engage in various acts of locomotion, as walking, running, dancing, swimming.

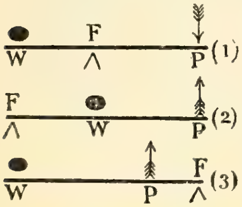

FIG. 41.—THE THREE ORDERS OF LEVERS.

Levers.—The function or special mode of action of individual muscles can be understood only when the bones with which they are connected are regarded as levers whose fulcra or fixed points lie in the joints where the movement takes place, and the muscles as sources of power for imparting movement to the levers with the object of overcoming resistance.

In mechanics levers of three kinds or orders are recognized according to the relative positions of the fulcrum or axis of motion, the applied power, and the weight to be moved. (See Fig. 41.)

In levers of the first order the fulcrum, F, lies between the weight or resistance, W, and the power or moving force, P. The distance P F is known as the power arm and the distance W F as the weight arm. As examples of this form of lever found in the human body may be mentioned:

1. The elevation of the trunk from the flexed position. The axis of movement, the fulcrum, lies in the hip-joint; the weight, that of the trunk, acting as if concentrated at the center of gravity, which lies close to the tenth dorsal vertebra; the power, the muscles attached to the tuberosity of the ischium. The opposite movement is equally one of the first order, but the relative positions of P and W are reversed.
2. The head in its movement backward and forward on the atlas.

In levers of the second order the weight lies between the power and the fulcrum. As illustration of this form of lever may be mentioned:

1. The depression of the lower jaw, in which movement the fulcrum is the temporomaxillary articulation; the resistance, the tension of the elevator muscles; the power, the contraction of the depressor muscles.
2. The raising of the body on the toes, in which movement the fulcrum is the toes, the weight that of the body acting through the ankle, the power the gastrocnemius muscle applied to the heel bone.

In levers of the third order the power is applied at a point lying between the fulcrum and the weight. As examples of this form of lever may be mentioned:

1. The flexion of the forearm, in which the fulcrum is the elbow-joint, the power the biceps and brachialis anticus muscles applied at their points of insertion, the weight that of the forearm and hand.
2. The extension of the leg on the thigh.

When levers are employed in mechanic operations, the object aimed at is the overcoming of a great resistance by the application of a small force acting through a great distance, so as to obtain mechanic advantage. In the mechanism of the human body the reverse generally obtains, viz., the overcoming of a small resistance by the application of a large force acting through a short distance. As a result there is a gain in the extent and rapidity of the movement of the lever. The power, however, owing to its point of application, acts at a great mechanic disadvantage in many instances, especially in levers of the third order.

Postures.—Owing to its system of joints, levers, and muscles the human body can assume a series of positions of equilibrium, such as standing and sitting, to which the term posture has been given. In order that the body may remain in a state of stable equilibrium in any posture, it is essential that the vertical line passing through its center of gravity shall fall within the base of support.

Standing is that position of equilibrium in which a line drawn through the center of gravity of the entire body falls within the base of support. This position is maintained largely by the mechanical conditions of the joints, apparently for the purpose of reducing to a minimum muscular action, so that it can be prolonged for some time without giving rise to fatigue. In the military position, which may be assumed as the normal position, all the joints must be in such a condition of extension and fixation that the body will represent a rigid column resting on the astragalus and supported by the arch of the foot. This is accomplished:

1. By balancing the head on the apex of the vertebral column. This is done by the action of the muscles on the back of the neck. The muscular effort is, however, very slight, as the center of gravity of the head lies but a short distance in front of the articulation.

2. By making the vertebral column erect and rigid. This is brought about by the action of the common extensor muscles of the trunk. In this condition the center of gravity lies just in front of the tenth dorsal vertebra. The head, trunk, and upper extremities are now supported by the hip-joints; and in order that this support may give to the body a certain degree of stable equilibrium, independent of muscular action, the line of gravity falls behind the line uniting the center of rotation of the two joints. In consequence the body would fall backward were it not prevented by the tension of the iliofemoral ligament and the fascia lata.

The line of gravity, continued downward, passes through the knee-joint posterior to the axis of rotation, and hence the body would now fall backward were it not prevented by the tension of the lateral ligaments and the contraction of the quadriceps femoris muscle. Though the body is supported by the astragalus, the line of gravity does not pass through the line uniting the two joints, for in so doing constant muscular effort would be required to maintain stable equilibrium; passing a short distance in advance of this line, there would be a tendency of the body to fall forward, which is prevented by the extensor muscles of the foot. When the body is in the erect or military position, the center of gravity lies between the sacrum and last lumbar vertebra. Standing is thus an act of balancing, and requires not only the static conditions of joints, but the dynamic conditions of various groups of muscles, and hence is not a position of absolute ease and cannot be maintained for any length of time without experiencing discomfort and fatigue. Sitting erect is an attitude of equilibrium in which the body is balanced on the tubera ischii, when the head and trunk together form a rigid column.

Locomotion is the act of transferring the body as a whole through space, and is accomplished by the combined action of its own muscles. The acts involved consist of walking, running, jumping, etc.

Walking is a complicated act involving almost all the voluntary muscles of the body either for purposes of progression or for balancing the head and trunk, and may be defined as a progression in a forward horizontal direction due to the alternate action of both legs. In walking one leg becomes for the time being the active or supporting leg, carrying the trunk and head; the other the passive but progressing leg, to become in turn the active leg when the foot touches the ground. Each leg is therefore alternately in an active and passive state.

Running is distinguished from walking by the fact that at a given moment both feet are off the ground and the body is raised in the air.

THE VISCERAL MUSCLE.

The **visceral muscle,** as the name implies, is found in the walls of hollow viscera, where it is arranged in the form of a membrane or sheet. It is present in the walls of the alimentary canal, blood-vessels, respiratory tract, ureter, bladder, vas deferens, uterus, fallopian tubes, iris, etc. In some situations it is especially thick and well developed—*e. g.*, uterus and pyloric end of the stomach; in others it is thin and slightly developed.

The Histology of the Visceral Muscle-fiber.—When examined with the microscope, the muscle sheet is seen to be composed of fibers, narrow, elongated, and fusiform in shape. As a rule, they are extremely small, measuring only from 40 to 250 micromillimeters in length and from 4 to 8 micromillimeters in breadth. The center of each fiber presents a narrow, elongated nucleus. The muscle-protoplasm which makes up the body of the fiber appears to be enclosed by a delicate elastic membrane resembling in some respects the sarcolemma of the skeletal muscle. In some animals the visceral fiber presents a longitudinal striation suggesting the existence of fibrillæ surrounded by sarcoplasm (Fig. 42). The fibers are united longitudinally and transversely by a cement material. The muscle is increased in thickness by the superposition of successive layers. At varying intervals the fibers are grouped into bundles or fasciculi by septa of connective tissue (Fig. 43.) Blood-vessels ramify in the connective tissue and furnish the necessary nutritive material.

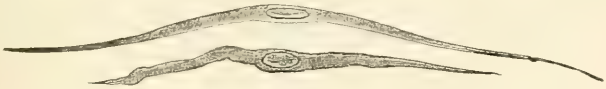

FIG. 42.—TWO SMOOTH MUSCLE-FIBERS FROM SMALL INTESTINE OF FROG. × 240. Isolated with 35 per cent. potash-lye. The nuclei have lost their characteristic form through the action of the lye.—(*Stöhr.*)

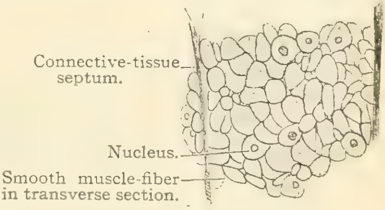
Connective-tissue septum.
Nucleus.
Smooth muscle-fiber in transverse section.

FIG. 43.—SECTION OF THE CIRCULAR LAYER OF THE MUSCULAR COAT OF THE HUMAN INTESTINE.—(*Stöhr.*)

The visceral muscle receives stimuli from the spinal cord, not directly, however, as in the case of the skeletal muscle, but indirectly through the intermediation of ganglion cells, which may be located at some distance from the muscle or near the walls of the viscera. Non-medullated fibers from the ganglion pass directly into the muscle, where they frequently unite to form a general plexus. From this plexus fine branches take their origin and ultimately become physiologically associated with the muscle-fiber.

Physiologic Properties.—The visceral muscles which have been subjected to experiment are mainly those of the stomach, intestine, bladder, ureter, and iris. From the results of the experiments which have been published, it is evident that all visceral muscles possess elasticity, tonicity, irritability, and conductivity.

The **elasticity** of the bladder muscle of the cat was strikingly shown in the experiments published by Dr. Colin C. Stewart. When this muscle was weighted with weights differing by a common increment, it was extended on the addition of each weight, though to a progressively less extent. On the removal of the weights the muscle eventually returned to its former length. The records of the extension were similar to, if not identical with, those of the skeletal muscle.

Tonicity is a property common to all visceral muscles. Each muscle is continuously in a state of contraction intermediate between that of complete contraction and that of relaxation. In how far this is due to local and inherent causes or to stimuli reflected from the nervous system as a result of peripherally acting causes is not in individual instances readily determinable. From time to time the tonicity varies, increasing and decreasing in response to these various stimuli and in accordance with the functional activities of the organs in which the muscle is found.

The **irritability** manifests itself by a change of form, and doubtless by the liberation of heat on the application of any form of stimulus—mechanic, chemic, thermic, electric.

The **conductivity** is less marked in the visceral than in the skeletal muscle, and, contrary to what is observed in the latter, the conduction extends laterally as well as longitudinally from fiber to fiber. This is shown by stimulation of the exposed intestine. Shortly after the stimulus is applied the muscle contracts longitudinally—*i. e.*, in a direction at right angles to the long axis of the intestine, partially obliterating its lumen. From this point the conduction process indicated by the contraction wave passes in opposite directions for some distance along the canal. As to whether this is accomplished by protoplasmic processes extending from fiber to fiber, or whether the uniting membrane differs in conducting power from the sarcolemma, is as yet a matter of doubt. From the fact that the upper two-thirds of the ureter, though free of nerve-cells, exhibits lateral conduction, it is evident that it may take place independent of the nervous system.

The Contraction of the Visceral Muscle.—The general character of the contraction may be witnessed on opening the abdomen of a recently killed animal, especially the rabbit. Shortly after exposure to the air the walls of the intestine begin to contract in a most vigorous manner. The contraction wave beginning at various points is propagated in both directions, running along the intestinal wall for a variable distance. A succession of similar waves may be observed for some minutes. To the alternate contraction and relaxation of the muscle-fibers, which are circularly arranged, the term peristalsis is usually given. The excised stomach of a dog kept under suitable conditions will exhibit similar movements. The same holds true of the bladder muscle of the cat, the muscle of the ureter, etc. Careful observation shows a certain periodicity in the movements. Inasmuch as the cause is not apparent, these contractions are termed spontaneous or automatic.

Graphic Record of the Contraction.—For experimental purposes narrow transverse sections of the stomach of the frog or the entire bladder muscle of the cat, excised or *in situ*, according to the method of Prof. Colin C. Stewart, may be employed. If kept moist, they will retain their irritability for some hours. The changes of form may be recorded with the usual muscle lever. When thus prepared, the muscle may exhibit for several hours a series of pulsations, rhythmic in character. With spontaneously acting mammalian muscle the contraction and relaxation periods are of equal duration. With the amphibian muscle they are of unequal duration, as a rule. In both classes of animals the character of the record, a succession of large and small contractions, would indicate that the general rhythmic movement is compounded of two or three secondary rhythms which differ in rate and character. A single pulsation may be recorded by stimulating the bladder muscle with the induced or the make and break of the constant current. A curve of such a contraction is shown in Fig. 44. The contraction takes place more rapidly than the relaxation; the two phases occupying five and thirty-five seconds respectively. The latent period covered 0.25 second. With other muscles the time relations are slightly different. Tetanization of the bladder muscle of the cat occurred when the stimuli succeeded each other with a certain rapidity; the interval between stimuli approximating a period somewhat less than two seconds. This muscle responds to variations in temperature, to strength of stimulus, to the load, in a manner similar to, if not identical with, the skeletal muscle.

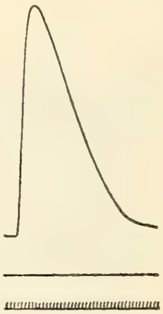

FIG. 44.—THE CURVE OF CONTRACTION OF THE BLADDER MUSCLE AT BODY-TEMPERATURE IN RESPONSE TO A SINGLE INDUCTION CURRENT. THE TIME IS INDICATED IN SECONDS.—(*Stewart.*)

The Function of the Visceral Muscle.—In a general way it may be said that the visceral muscle determines and regulates the passage through the viscus or organ of the material contained within it. The food in the stomach and intestines is subjected to a churning process by the muscles, in consequence of which the digestive fluids are more thoroughly incorporated and their characteristic action increased. At the same time the food is carried through the canal, the absorption of the nutritive material promoted, and the indigestible residue removed from the body. The blood is delivered in larger or smaller volumes according to the needs of the tissues through a relaxation or contraction of the muscle-fibers of the blood-vessels. The urine is forced through the ureter and from the bladder by the contraction of their respective muscles. The mode of action of the individual muscles will be described in successive chapters.

Ciliary Movement.—The free surface of the epithelium covering the mucous membrane in certain regions of the body is characterized by the presence of delicate filamentous processes termed cilia. (See Fig. 45.) Ciliated epithelium is found in man and mammals generally, in the nose, Eustachian tube, larynx, with the exception of the vocal membranes, trachea and bronchial tubes as far as the pulmonary lobules, Fallopian tubes, uterus, and epididymis. The lumen of the central canal of the spinal cord and the cavities of the brain are lined, especially in childhood, by cells provided with similar cilia. Ciliated epithelium is also found in all classes of animals, and especially in the invertebrates.

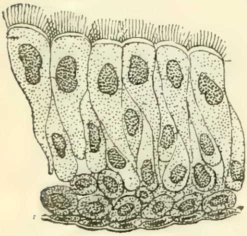

Fig. 45.—Ciliated Epithelium.

The cilia found in the human body vary in length from 0.003 mm. to 0.005 mm. They are apparently structureless and colorless, and appear to have their origin in and to be a prolongation of a transparent material on the outer surface of the cell material. The number of cilia present on the surface of any individual cell varies approximately from five to twenty-five. When ciliated epithelial cells, freshly removed from the mucous membrane and moistened with normal saline, are examined with the microscope, it will be found that the cilia are in continuous and rapid vibratile movement, so much so that the individual cilium can not be distinguished. In time, however, their vitality declines and the rapidity of movement diminishes. When the movement of the individual cilium falls to about eight or ten per second, its character can be readily determined. It will then be seen that the movement is, as a rule, alternately a backward and a forward one, the cilium lowering and then raising itself, the latter taking place more quickly and energetically than the former. As the cilium raises itself it becomes somewhat flexed in a direction corresponding to that of the general movement. The movement, however, varies in character in different situations and in different animals. The cause of the movements and the mechanism of their coördination are unknown. They are, as far as known, independent of the nerve system. The force of ciliary motion is very great. A load of twenty grams can be supported and carried forward by the cilia on the mucous membrane of the mouth and esophagus of the frog. The activity of the cilia is associated with the nutrition of the cell of which they are a part and rises and falls with it. Experimentally it has been found that the rate and energy of the movement are greatest at a temperature of about 35° to 40° C., especially if they are bathed with normal saline, rendered slightly alkaline. Low temperatures, acids, alkalies, carbon dioxid, etc., retard the movement.

The function of the cilia, though not always apparent, is associated with the function of the passages in which they are found. As the surfaces of these passages are swept by a current of considerable power, it is probable that they assist in the passage of the materials which ordinarily traverse them. Mucus and particles of dust are carried upward through the air-passages; the ovarian cell is carried from the ovary toward the uterus; the spermatozoa, as well as the fluid in which they are contained, are carried forward through the epididymis ducts.

CHAPTER VIII.

THE GENERAL PHYSIOLOGY OF NERVE-TISSUE.

The **nerve-tissue,** which unites and coördinates the various organs and tissues of the body and brings the individual into relationship with the external world, is arranged in two systems, termed the *encephalospinal* or *cerebrospinal* and the *sympathetic.*

The **encephalospinal system** consists of:

1. The brain and spinal cord, contained within the cavities of the cranium and the spinal column respectively, and
2. The cranial and spinal nerves.

The **sympathetic system** consists of:

1. A double chain of ganglia situated on each side of the spinal column and extending from the base of the skull to the tip of the coccyx.
2. Various collections of ganglia situated in the head, face, thorax, abdomen, and pelvis. All these ganglia are united by an elaborate system of intercommunicating nerves, many of which are connected with the cerebrospinal system.

HISTOLOGY OF NERVE-TISSUE.

The Neuron.—The nerve-tissue has been resolved by the investigations of modern histologists into a single morphologic unit, to which the term neuron has been applied. The entire nerve system has been shown to be but an aggregate of an infinite number of neurons, each of which is histologically distinct and independent. Though having a common origin, as shown by embryologic investigations, they have acquired a variety of forms in different parts of the nervous system in the course of development. The old conception that the nerve system consisted of two distinct histologic elements, nerve-cells and nerve-fibers, which differed not only in their mode of origin, but also in their properties, their relation to each other, and their functions, has been entirely disproved.

The neuron, or neurologic unit, is histologically a nerve-cell, the surface of which presents a greater or less number of processes in varying degrees of differentiation. As represented in Figure 46, A, the neuron may be said to consist of: (1) The nerve-cell, neurocyte, or corpus; (2) the axon, or nerve process; (3) the end-tufts, or terminal branches. Though these three main histologic features are everywhere recognizable, they exhibit a variety of secondary features in different situations in accordance with peculiarities of function.

Though the nerve-cell and the nerve-fiber are but part of the same neuron, it is convenient at present to describe them separately.

The Nerve-cell.—The nerve-cell, or body of the neuron, presents a variety of shapes and sizes in different portions of the nervous system. Originally ovoid in shape, it has acquired, in course of development, peculiarities of form which are described as pyramidal, stellate, pear-shaped, spindle-shaped, etc. The size of the cell varies considerably, the smallest having a diameter of not more than $\frac{1}{3000}$ of an inch, the largest not more than $\frac{1}{400}$ of an inch. Each cell consists of granular, striated protoplasm, containing a distinct vesicular nucleus and a well-defined nucleolus. A cell membrane has not been observed. From the surface of the adult cell portions of the protoplasm are projected in various directions, which portions, rapidly dividing and subdividing, form a series of branches, termed *dendrites* or *dendrons.* In some situations the ultimate branches of the dendrites present short lateral processes, known as *lateral buds*, or *gemmules*, which impart to the branches a feathery appearance. This characteristic is common to the cells of the cortex of the cerebrum and of the cerebellum. The ultimate branches of the dendrites, though forming an intricate felt-work, never anastomose with one another nor unite with dendrites of adjoining cells. According to the number of axons, nerve-cells are classified as monaxonic, diaxonic, polyaxonic. Most of the cells of

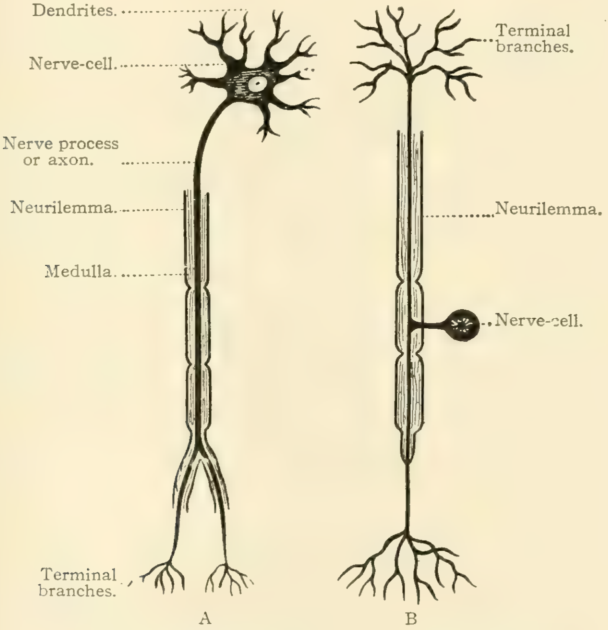

FIG. 46.—A. Efferent neuron. B. Afferent neuron.

the nervous system of the higher vertebrates are monaxonic. In the ganglia of the posterior or dorsal roots of the spinal and cranial nerves, however, they are diaxonic. In this situation the axons, emerging from opposite poles of the cell, either remain separate and pursue opposite directions, or unite to form a common stem, which subsequently divides into two branches, which then pursue opposite directions. (See Fig. 46, B.) The nerve-cell maintains its own nutrition, and presides over that of the dendrites and the axon as well. If the latter be separated in any part of its course from the cell, it speedily degenerates and dies.

The *axon*, or *nerve process*, arises from a cone-shaped projection from the surface of the cell, and is the first outgrowth from its protoplasm. At a short distance from its origin it becomes markedly differentiated from the dendrites which subsequently develop. It is characterized by a sharp, regular outline, a uniform diameter, and a hyaline appearance. In structure, the axon appears to consist of fine fibrillæ embedded in a clear, protoplasmic substance. Shäfer advocates the view that the fibrillæ are exceedingly fine tubes filled with fluid. The axon varies in length from a few millimeters to one meter. In the former instance the axon, at a short distance from its origin, divides into a number of branches, which form an intricate feltwork in the neighborhood of the cell. In the latter instance the axon continues for an indefinite distance as an individual structure. In its course, however, especially in the brain and spinal cord, it gives off a number of *collateral* branches, which possess all its histologic features. The long axons serve to bring the body of the cell into direct relation with peripheral organs, or with more or less remote portions of the nerve system, thus constituting association or commissural fibers.

The more or less elongated axon becomes invested, as a rule, at a short distance from the cell with nucleated oblong cells, which subsequently become modified and constitute the medullary or myelin sheath. This is invested by a thin, cellular membrane—the neurilemma. These three structures thus constitute what is known as a *medullated nerve-fiber*. In the brain and spinal cord the outer sheath, however, is frequently absent. In the sympathetic system the myelin is also frequently absent, though the axon is inclosed by the neurilemma, thus constituting a *non-medullated nerve-fiber*.

The *end-tufts* or *terminal organs* are formed by the splitting of the axon into a number of filaments, which remain independent of one another and are free from the medullary investment. The histologic peculiarities of the terminal organs vary in different situations, and in many instances are quite complex and characteristic. In peripheral organs, as muscles, glands, blood-vessels, skin, mucous membrane, the tufts are in direct histologic and physiologic connection with their cellular elements. In the brain and spinal cord the tufts are in more or less intimate relation with the dendrites of adjacent neurons.

The neurons in their totality constitute the neuron or nerve tissue. From the fact that they are arranged both serially and collaterally into a regular and connected whole, they collectively constitute a system known as the neuron or nerve system.

Neurons, moreover, are grouped into more or less completely organized masses, termed organs, which in accordance with their locations may for convenience be divided into central and peripheral organs. The central organs of the nerve system consist of the encephalon or brain and the spinal cord; the peripheral organs consist of the cranial nerves, the spinal nerves, the sympathetic ganglia and their branches.

Nerve-fibers.—The nerve-fibers which constitute by far the larger part of both the peripheral and central organs of the nerve system, are simply the axonic processes of neurons with their secondary investments, the myelin and neurilemma; according as they possess or do not possess the medullary sheath, they may be divided into two groups—viz., medullated and non-medullated fibers.

Medullated Nerve-fibers.—These consist for the most part of three distinct structures:

1. An external investing sheath, tubular in shape, termed the neurilemma.
2. An intermediate semifluid substance—the medulla or myelin.
3. An internal dark thread—the axis-cylinder.

The *neurilemma* is a thin, transparent, homogeneous membrane closely adherent to the medulla. Owing to its colorless appearance, it can be seen only with difficulty in fresh tissue. When treated with various reagents, it becomes distinct. Physically, it is quite resistant and elastic. Its function is doubtless that of a protective agent to the structures within.

The *medulla*, *myelin*, or *white substance of Schwann* completely fills the neurilemma and closely invests the axis-cylinder or axon. In fresh tissue the medulla is clear, homogeneous, semifluid, and highly refracting. When the nerve is treated with various reagents which alter its composition, the medulla becomes opaque and imparts a white, glistening appearance. The function of the medulla is quite unknown.

At intervals of about seventy-five times its diameter the medullated nerve-fiber undergoes a remarkable diminution in size, due to an interruption of the medullary substance, so that the neurilemma lies directly on the axis-cylinder. These constrictions, or *nodes of Ranvier*, taking their name from their discoverer, occur at regular intervals along the course of the nerve, separating it into a series of segments. The portion between the nodes is termed the internodal segment. It has been suggested that in consequence of the absence of the myelin at these nodes, a free exchange of nutritive material and decomposition products can take place between tbe axis-cylinder and the surrounding plasma. Beneath the neurilemma in each internodal segment there is a large nucleus surrounded by a small amount of granular protoplasm.

The *axis-cylinder,* or axon, the direct outgrowth of the nerve-cell, is the most essential element of the nerve-fiber, as it alone is uniformly continuous throughout. In the natural condition it is transparent and invisible; but when treated with proper reagents, it presents itself as a pale, granular, flattened band, more or less solid and somewhat elastic. It is albuminous in composition. With high magnification the axis presents a longitudinal striation, indicating a fibrillar structure. The fibrillæ appear to be embedded in an intervening semifluid substance, the neuroplasm.

Non-Medullated Nerve-fibers.—These consist, for the most part, only of the axis-cylinder, though in some portions of the nerve system a neurilemma is also present. Though much less abundant than the former variety, they are distributed largely throughout the nerve system, but are particularly abundant in the sympathetic. Owing to the absence of a medulla, they present a rather pale or grayish appearance.

Sympathetic Ganglia.—A sympathetic ganglion consists essentially of a connective-tissue capsule with an interior framework. The meshes of this framework contain nerve-cells provided with dendrites and branching axons. The majority of the axons are non-medullated. In all instances, with the exception of the ganglion cells of the heart, the axons are distributed to non-striated muscle tissue and to the epithelium of glands.

The nerve-cells of the ganglia are also in histologic connection with the terminal branches of fine medullated nerve-fibers which leave the spinal cord by way of the anterior roots of the spinal nerves. These nerve-fibers are designated *autonomic* or *pre-ganglionic* fibers, while those emerging from the cells are designated *post-ganglionic* fibers. (See Sympathetic System.)

The Peripheral Organs of the Nerve System.—These consist of the cranial and spinal nerves and the sympathetic ganglia. Each nerve consists of a variable number of nerve-fibers united into firm bundles by connective tissue which supports blood-vessels and lymphatics. The bundles are technically known as *nerve-trunks* or *nerves.*

The nerve-trunks connect the brain and cord with all the remaining structures of the body. Each nerve is invested by a thick layer of lamellated connective tissue, known as the *epineurium.* A transverse section of a nerve shows (see Fig. 47) that it is made up of a number of small bundles of fibers, each of which possesses a separate investment of connective tissue—the *perineurium.* Within this membrane the nerve-fibers are supported by a fine stroma—the *endoneurium.* After pursuing a longer or shorter course, the nerve-trunk gives off branches, which interlace very freely with neighboring branches, forming plexuses, the fibers of which are distributed to associated organs and regions of the body. From their origin to their termination, however, nerve-fibers retain their individuality, and never become blended with adjoining fibers.

As nerves pass from their origin to their peripheral terminations, they give off a number of branches, each of which becomes invested with a lamellated sheath—an offshoot from that investing the parent trunk. This division of nerve-bundles and sheath continues throughout all the branchings down to the ultimate nerve-fibers, each of which is surrounded by a sheath of its own, consisting of a single layer of endothelial cells. This delicate transparent membrane, the sheath of Henle, is separated from the nerve-fiber by a considerable space, in which is contained lymph destined for the nutrition of the fiber. Near their ultimate terminations the nerve-fibers themselves undergo division, so that a single fiber may give origin to a number of branches, each of which contains a portion of the parent axis-cylinder and myelin.

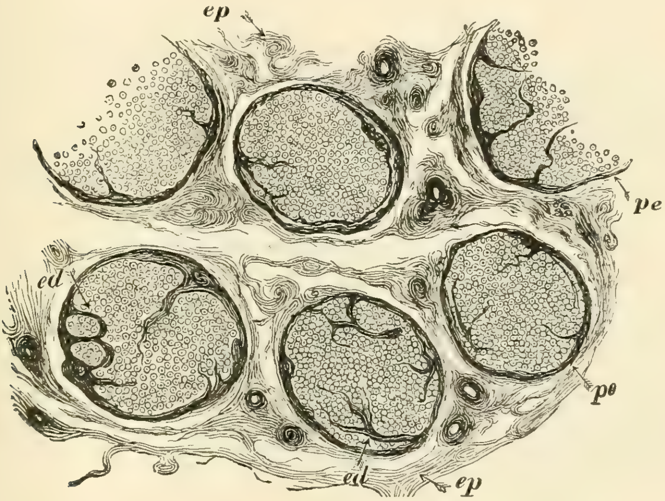

Fig. 47.—Transverse Section of a Nerve (Median). *ep.* Epineurium. *pe.* Perineurium. *ed.* Endoneurium.—(*Landois and Stirling.*)

Blood-supply.—Nerves being parts of living cells require for the maintenance of their nutrition a certain amount of blood. This is furnished by the blood-vessels ramifying in and supported by the connective-tissue framework. Here as elsewhere there is a constant exchange, through the capillary wall and the neurilemma, of nutritive material to the nerve proper and of waste materials to the blood.

The Chemic Composition and Metabolism.—Chemic analysis of nerve-tissue has shown the presence of water, proteins (two globulins and a nucleo-protein), neurokeratin and nuclein, two phosphorized bodies (protagon and lecithin), several cerebrosides (nitrogen-holding bodies of a glucoside character, as shown by their yielding the reducing carbohydrate galactose), inorganic salts, and a series of nitrogen-holding bodies such as creatin, xanthin, urea, leucin, etc. As to the metabolism that is taking place in nerve-cells and fibers, practically nothing definite is known. That such changes, however, are taking place would be indicated first by the blood-supply, and second by the fact that withdrawal of the blood-supply is followed by a loss of irritability. The metabolism of the central organs of the nerve system is more active and extensive. In this situation any withdrawal of blood from compression or occlusion of blood-vessels is followed by impairment of nutrition and loss of function.

THE RELATION OF THE PERIPHERAL ORGANS OF THE NERVE SYSTEM TO THE CENTRAL ORGANS.

Spinal Nerves.—The nerves in connection with the spinal cord are thirty-one in number on each side. If traced toward the spinal column, it will be found that the nerve-trunk passes through an intervertebral foramen. Near the outer limits of the foramina each nerve-trunk divides into two branches, generally termed roots, one of which, curving slightly forward and upward, enters the spinal cord on its anterior or ventral surface, while the other, curving backward and upward, enters the spinal cord on its posterior or dorsal surface. The former is termed the anterior or ventral root; the latter, the posterior or dorsal root. Each dorsal root presents near its union with the ventral root a small ovoid grayish enlargement known as a ganglion. Both roots previous to entering the cord subdivide into from four to six fasciculi.

A microscopic examination of a cross-section of the spinal cord shows that the fibers of the ventral roots can be traced directly into the body of the nerve-cells in the ventral horns of the gray matter. The fibers of the dorsal roots are not so easily traced, for they diverge in several directions shortly after entering the cord. In their course they give off collateral branches which, in common with the main fiber, end in tufts which become associated with nerve-cells in both the ventral and dorsal horns of the gray matter.

Cranial Nerves.—The nerves in connection with the base of the brain are known as cranial nerves; some of these nerves present a similar ganglionic enlargement, and therefore may be regarded as dorsal nerves, while others may be regarded as ventral nerves. Their relations within the medulla oblongata are similar to those within the spinal cord.

Efferent and Afferent Nerves.—Nerves are channels of communication between the brain and spinal cord, on the one hand, and the muscles, glands, blood-vessels, skin, mucous membrane, viscera, etc., on the other. Some of the nerve-fibers serve for the transmission of nerve energy from the brain and spinal cord to certain peripheral organs, and so increase or retard their activities; others serve for the transmission of nerve energy from certain peripheral organs to the brain and spinal cord which gives rise to sensation or other modes of nerve activity. The former are termed *efferent* or *centrifugal*, the latter *afferent* or *centripetal* nerves. Experimentally it has been determined that the anterior or ventral roots contain all the *efferent* fibers, the posterior or dorsal roots all the *afferent* fibers.

THE PERIPHERAL ENDINGS OF NERVES.

The efferent nerves as they approach their ultimate terminations lose both the neurilemma and myelin sheath. The axon or axis-cylinder then divides into a number of branches which become directly and intimately associated with tissue-cells. The particular mode of termination varies in different situations. These terminations are generally spoken of as end-organs, terminal organs, or end-tufts.

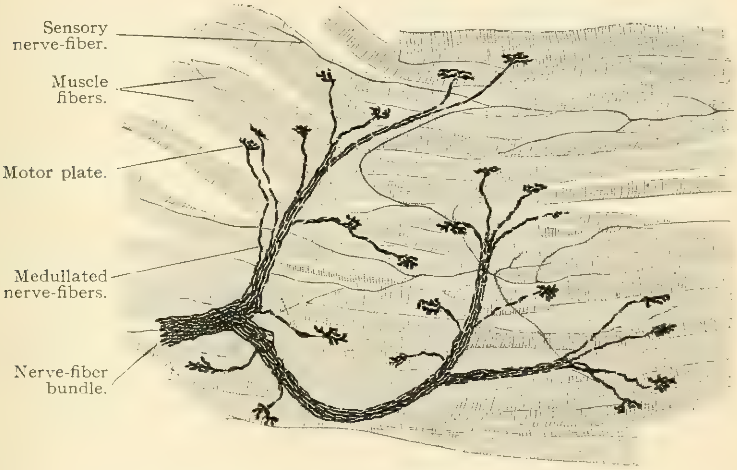

Fig. 48.—Motor Nerve-endings of Intercostal Muscle-fibers of a Rabbit. × 150.—(*Stöhr.*)

In the *skeletal* muscle the nerve-fiber loses both neurilemma and myelin sheath at the point where it comes in contact with the muscle-fiber. After penetrating the sarcolemma, the axon or axis-cylinder divides into a number of small branches which appear to be embedded in a relatively large mass of sarcoplasm and nuclei, the whole forming the so-called "motor plate." Each muscle-fiber possesses one such plate or end-organ in mammalia, several in the frog. (Fig. 48.)

In the *visceral* muscle the terminal nerve-fibers derived from sympathetic or peripheral neurons are primarily non-medullated. The axons divide and subdivide and form plexuses which surround the muscle-cell bundles. Fine fibers from the plexuses are given off which ultimately come into relation with each individual cell, on the surface of which they terminate in the form of one or more granular masses.

In the *glands*, taking as an illustration the parotid and mammary glands, the nerve-fibers, also derived from sympathetic or peripheral neurons, pass into the body of the gland and ultimately reach the acini, on the outer surface of which they ramify and form a plexus. From this plexus fine fibers penetrate the acinus wall and end on the gland-cell. The fibers present a varicose appearance (Fig. 49).

The afferent nerves as they approach their ultimate terminations undergo similar changes. The end-tufts become associated, in some situations, with specialized end-organs which are extremely complex; *e. g.*, the retina in the eye, the organ of Corti in the ear, the taste-beakers in the tongue, the olfactory cells in the nose.

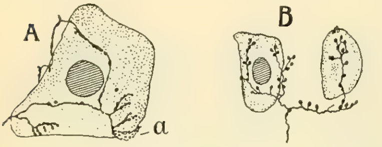

FIG. 49.—TERMINATIONS OF NERVE-FIBERS IN THE GLAND-CELLS. A. Cell of the parotid gland of a rabbit. B. Cells of the mammary gland of a cat in gestation.—(*Doyon and Morat.*)

In the *skin* and *mucous* membranes the mode of termination varies considerably. The following are some of the principal modes:

1. Free endings in the epithelium.
2. Tactile cells of Merkel.
3. Tactile corpuscles in the papillæ of the true skin.
4. Pacinian corpuscles found attached to the nerves of the hand and feet, to the intercostal nerves, and to nerves in other situations.
5. End-bulbs of Krause in the conjunctiva, clitoris, penis, etc.

(A consideration of these end-organs will be found in the chapters devoted to the organs of which they form a part.)

In the *skeletal muscles* afferent fibers become associated with small spindle-shaped structures known as muscle-spindles or neuromuscle end-organs. These spindles vary in length from 1 mm. to 4 mm. They consist of a capsule of fibrous tissue containing from five to twenty muscle-fibers. After penetrating the several layers of the capsule, the nerve-fibers lose the neurilemma and myelin sheaths. The axons or axis-cylinders then divide into several long narrow branches which wind themselves in a spiral manner around the contained muscle-fiber and terminate in small oval-shaped discs. Similar endings have been observed in the tendons of muscles.

Development and Nutrition of Nerves.—The **efferent nerve-fibers,** which constitute some of the cranial nerves and all the ventral roots of the spinal nerves, have their origin in cells located in the gray matter beneath the aqueduct of Sylvius, beneath the floor of the fourth ventricle, and in the anterior horns of the gray matter of the spinal cord. These cells are the modified descendants of independent, oval, pear-shaped cells—the neuroblasts—which migrate from the medullary tube. As they approach the surface of the cord their axons are directed toward the ventral surface, which eventually they pierce. Emerging from the cord, the axons continue to grow, and become invested with the myelin sheath and neurilemma, thus constituting the ventral roots.

The **afferent nerve-fibers,** which constitute some of the cranial nerves and all the dorsal roots of the spinal nerves, develop outside of the central nervous system and only subsequently become connected with it. (See Fig. 50.) At the time of the closure of the medullary tube a band or ridge of epithelial tissue develops near the dorsal surface, which, becoming segmented, moves outward and forms the rudimentary spinal ganglia. The cells in this situation develop two axons, one from each end of the cell, which pass in opposite directions, one toward the spinal cord, the other toward the periphery. In the adult condition the two axons shift their position, unite, and form a T shaped process, after which a division into two branches again takes place. In the ganglia of all the sensori-cranial and sensori-spinal nerves the cells have this histologic peculiarity.

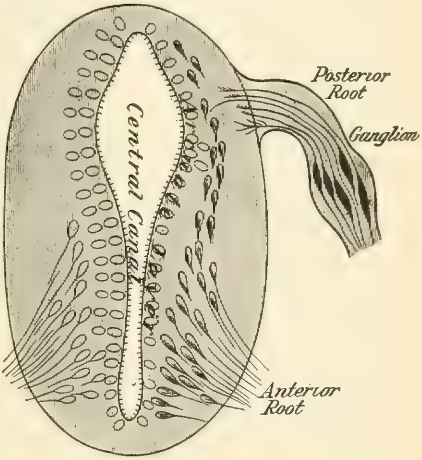

Fig. 50.—Diagram Showing the Mode of Origin of the Ventral and Dorsal Roots.—(*Edinger, after His.*)

The efferent fibers are therefore to be regarded as outgrowths from the nerve-cells in the ventral horns of the gray matter, and serve to bring the cells into anatomic and physiologic relationship directly with the skeletal muscles and indirectly, through the intermediation of ganglia (see sympathetic nervous system), with visceral muscles and glands.

The afferent fibers are to be regarded as outgrowths from the cells of the dorsal nerve ganglia, and serve to bring the skin, mucous membrane, and certain visceral structures into relation with specialized centers in the central nerve system.

Nerve Degeneration.—If any one of the cranial or spinal nerves be divided in any portion of its course, the part in connection with the periphery in a short time exhibits certain structural changes, to which the term degeneration is applied. The portion in connection with the brain or cord retains its normal condition with the exception of a few millimeters at its peripheral end. The degenerative process begins simultaneously throughout the entire course of the nerve, and consists in a disintegration and reduction of the myelin and axis-cylinder into nuclei, drops of myelin, and fat, which in time disappear through absorption, leaving the neurilemma intact. Coincident with these structural changes there is a progressive alteration and diminution in the excitability of the nerve. Inasmuch as the central portion of the nerve, which retains its connection with the nerve-cell, remains histologically normal, it has been assumed that the nerve-cells exert over the entire course of the nerve-fibers a nutritive or a trophic influence. This idea has been greatly strengthened since the discovery that the axis-cylinder, or the axon, has its origin in and is a direct outgrowth of the cell. When separated from the parent cell, the fiber appears to be incapable in itself of maintaining its nutrition.

The relation of the nerve-cells to the nerve-fibers, in reference to their nutrition, is demonstrated by the results which follow section of the ventral and dorsal roots of the spinal nerves. If the anterior root alone be divided, the degenerative process is confined to the peripheral portion, the central portion remaining normal. If the posterior root be divided on the peripheral side of the ganglion, degeneration takes place only in the peripheral portion of the nerve. (See Fig. 51.) If the root be divided between the ganglion and the cord, degeneration takes place only in the central portion of the root. From these facts it is evident that the trophic centers for the ventral and dorsal roots lie in the spinal cord and spinal nerve ganglia, respectively, or, in other words, in the cells of which they are an integral part. The structural changes which nerves undergo after separation from their centers are degenerative in character, and the process is usually spoken of, after its discoverer, as the *Wallerian degeneration.*

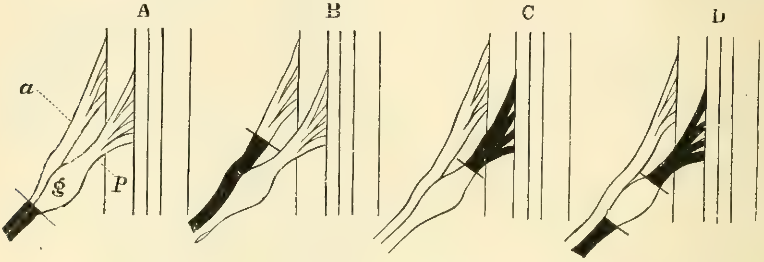

FIG. 51.—DEGENERATION OF SPINAL NERVES AND NERVE-ROOTS AFTER SECTION. A. Section of nerve-trunk beyond the ganglion. B. Section of anterior root. C. Section of posterior root. D. Excision of ganglion. *a*. Anterior root. *p*. Posterior root. *g*. Ganglion.—(*Dalton.*)

When the nerve-cells from which the nerve-fibers arise, whether efferent or afferent, undergo degeneration from any cause whatever, the nerve-fiber becomes involved in the degenerative process and when it is completed the structures to which they are distributed, especially the muscles, undergo an atrophic or fatty degeneration, with a change or loss of their irritability. This is, apparently, not to be attributed merely to inactivity, but rather to a loss of nerve influences, inasmuch as inactivity merely leads to atrophy and not to degeneration.

Reunion and Regeneration.—When a nerve-trunk is divided there is a loss of function of the parts to which it is distributed, and usually involves both motion and sensation. This, however, is not necessarily permanent, for after a variable period of time it not infrequently happens, that the functions are restored because of a reunion of the separated ends and a regeneration of the peripheral portion. A histologic study of the nerve-fibers after separation from the nerve-cells shows that coincidently with the degenerative process there occurs a regenerative process, consisting in a multiplication of the nuclei lying just beneath the neurilemma and an accumulation around them of a granular protoplasm which in due time completely fill the neurilemma. At this stage the fiber is known as a band-fiber. If now the physical conditions are such as to permit of a reunion of the nerve, this takes place, and under the nutritive influence of the cell the axis-cylinder grows into the band-fiber and the protoplasm becomes transformed into myelin as in the original fiber. The axis-cylinder continues to grow and extend itself forward until it reaches its ultimate termination.

CLASSIFICATION OF NERVES.

The **efferent nerves** may be classified, in accordance with the characteristic form of activity to which they give rise, into several groups, as follows:

1. *Skeletal-muscle* or *motor* nerves, those which convey nerve energy or nerve impulses to skeletal-muscles and excite them to activity.
2. *Gland* or *secretor* nerves, those which convey nerve impulses to glands, and cause the formation and discharge of the secretion peculiar to the gland.
3. *Vascular* or *vaso-motor* nerves, those which convey nerve impulses to the muscle-fibers of the blood-vessels and change in one direction or the other the degree of their natural contraction. Those which increase the contraction are known as vaso-constrictors or vaso-augmentors; those which decrease the contraction are known as vaso-dilatators or vaso-inhibitors. The nerves which pass to that specialized part of the vascular apparatus, the heart, transmit nerve impulses which on the one hand accelerate its rate or augment its force, and on the other hand inhibit or retard its rate and diminish its force. For this reason they are termed cardio-motor nerves, one set of which is known as accelerator and augmentor, the other as inhibitor nerves.
4. *Visceral* or *viscero-motor* nerves, those which transmit nerve impulses to the muscle walls of the viscera and change in one direction or another the degree of their contraction. Those which increase or augment the contraction are known as viscero-augmentor, while those which decrease or inhibit the contraction, are known as viscero-inhibitor nerves.

5. *Hair bulb* or *pilo-motor* nerves, those which transmit nerve impulses to the muscle-fibers which cause an erection of the hairs.

Of the foregoing nerves the skeletal-muscle or motor nerves alone pass directly to the muscle. The gland, the vascular and the visceral nerves, all terminate at a variable distance from the peripheral organ around a local sympathetic ganglion, which in turn is connected with the peripheral organ. The former are termed pre-ganglionic. The latter post-ganglionic fibers. (See Fig. 61.)

The **afferent nerves** may also be classified, in accordance with their distribution and the character of the sensations or other modes of nerve activity to which they give rise, into several groups, as follows:

1. *Tegumentary* nerves, comprising those distributed to skin, mucous membranes and sense organs and which transmit nerve impulses from the periphery to the nerve centers. They may be divided into sensorifacient and reflex nerves.
   - A. *Sensorifacient* nerves, those which transmit nerve impulses to the brain where they give rise to conscious sensations. They may be subdivided into:
     1. Nerves of special sense—*e. g.*, olfactory, optic, auditory, gustatory, tactile, thermal, pain, pressure—which give rise to correspondingly named sensations.
     2. Nerves of general sense—*e. g.*, the visceral afferent nerves—those which give rise normally to vague and scarcely perceptible sensations, such as the general sensations of well-being or discomfort, hunger, thirst, fatigue, sex, want of air, etc.
   - B. *Reflex* nerves, those which transmit nerve impulses to the spinal cord and medulla oblongata, where they give rise to different modes of nerve activity. They may be divided into:
     1. Reflex excitator nerves, which transmit nerve impulses which cause an excitation of nerve centers and in consequence increased activity of peripheral organs, *e. g.*, skeletal muscles, glands, blood-vessels and viscera.
     2. Reflex inhibitor nerves, which transmit nerve impulses which cause an inhibition of nerve centers and in consequence, decreased activity of the peripheral organs. It is quite probable that one and the same nerve may subserve both sensation and reflex action, owing to the collateral branches which are given off from the afferent roots as they ascend the posterior column of the cord.

Muscle nerves, comprising those distributed to muscles and tendons and which transmit nerve impulses from muscle and tendons to the brain where they give rise to the so-called muscle sensations, *e. g.*, the direction and the duration of a movement, the resistance offered and the posture of the body or of its individual parts.

PHYSIOLOGIC PROPERTIES OF NERVES.

Nerve Irritability or Excitability and Conductivity.—These terms are employed to express that condition of a nerve which enables it to develop and to conduct nerve impulses from the center to the periphery, or from the periphery to the center, in response to the action of stimuli. A nerve is said to be excitable or irritable so long as it possesses these capabilities or properties. For the manifestation of these properties the nerve must retain a state of physical and chemic integrity; it must undergo no change in structure or chemic composition. The irritability of an *efferent* nerve is demonstrated by the contraction of a muscle, by the secretion of a gland, or by a change in the caliber of a blood-vessel, whenever a corresponding nerve is stimulated. The irritability of an *afferent* nerve is demonstrated by the production of a sensation or a reflex action whenever it is stimulated. The irritability of nerves continues for a certain period of time after separation from the nerve-centers and even after the death of the animal, the time varying in different classes of animals. In the warm-blooded animals, in which the nutritive changes take place with great rapidity, the irritability soon disappears—a result due to disintegrative changes in the nerve, caused by the withdrawal of the blood-supply and other non-physiologic conditions. In cold-blooded animals, on the contrary, in which the nutritive changes take place relatively slowly, the irritability lasts, under favorable conditions, for a considerable time. Other tissues besides nerves possess irritability, that is, the property of responding to the action of stimuli—*e. g.*, glands and muscles, which respond by the production of a secretion or a contraction.

Independence of Tissue Irritability.—The irritability of nerves is distinct and independent of the irritability of muscles and glands, as shown by the fact that it persists in each a variable length of time after their histologic connections have been impaired or destroyed by the introduction of various chemic agents into the circulation. Curara, for example, induces a state of complete paralysis by modifying or depressing the conductivity of the end-organs of the nerves just where they come in contact with the muscles, without impairing the irritability of either nerve-trunks or muscles. Atropin induces complete suspension of gland activity by impairing the terminal organs of the secretor nerves just where they come into relation with the gland-cells, without destroying the irritability of either gland-cell or nerve.

Nerve Stimuli.—Nerves do not possess the power of spontaneously generating and propagating nerve impulses; they can be aroused to activity only by the action of an external stimulus. In the physiologic condition the stimuli capable of throwing the nerve into an active condition act for the most part on either the central or peripheral end of the nerve. In the case of motor nerves the stimulus to the excitation, originating in some molecular disturbance in the nerve-cells, acts upon the nerve-fibers in connection with them. In the case of sensor or afferent nerves the stimuli act upon the peculiar end-organs with which the sensor nerves are in connection, which in turn excite the nerve-fibers. Experimentally, it can be demonstrated that nerves can be excited by a sufficiently powerful stimulus applied in any part of their extent.

Nerves respond to stimulation according to their habitual function; thus, stimulation of a sensor nerve, if sufficiently strong, results in the sensation of pain; of the optic nerve, in the sensation of light; of a motor nerve, in contraction of the muscle to which it is distributed; of a secretor nerve, in the activity of the related gland, etc. It is, therefore, evident that peculiarity of nerve function depends neither upon any special construction or activity of the nerve itself nor upon the nature of the stimulus, but entirely upon the peculiarities of its central and peripheral end-organs.

Nerve stimuli may be divided into—

1. *General stimuli*, comprising those agents which are capable of exciting a nerve in any part of its course.
2. *Special stimuli*, comprising those agents which act upon nerves only through the intermediation of the end-organs.

The end-organs are specialized highly irritable structures placed between the nerve-fibers and the surface. They are especially adapted for the reception of special stimuli and for the liberation of energy, which in turn excites the nerve-fiber to activity.

General stimuli:

1. Mechanic: Sharp taps, sudden pressure, cutting, etc.
2. Thermic: Sudden application of heated object.
3. Chemic: Contact of various substances which alter their chemic composition quickly, *e. g.*, strong acids or alkalies, sol. sodium chlorid 15 per cent., sugar, urea, etc.
4. Electric: Either the constant or induced current.

Special stimuli:

For afferent nerves—

1. Light or ethereal vibrations acting upon the end-organs of the optic nerve in the retina.
2. Sound or atmospheric undulations acting upon the end-organs of the auditory nerve.
3. Heat or vibrations of the air acting upon the end-organs in the skin.
4. Chemic agencies acting upon the end-organs of the olfactory and gustatory nerves.

For efferent nerves—

A molecular disturbance in the central nerve-cells from which they arise, the nature of which is unknown.

Nature of the Nerve Impulse.—As to the nature of the nerve impulse generated by any of the foregoing stimuli, either general or special, but little is known. It has been supposed to partake of the nature of a molecular disturbance, a combination of physical and chemic processes attended by the liberation of energy, which propagates itself from molecule to molecule. The passage of the nerve impulse is accompanied by changes of electric tension, the extent of which is an indication of the intensity of the molecular disturbance. Judging from the deflections of the galvanometer needle it is probable that when the nerve impulse makes its appearance at any given point it is at first feeble, but soon reaches a maximum development, after which it speedily declines and disappears. It may, therefore, be graphically represented as a wave-like movement with a definite length and time duration. Under strictly physiologic conditions the nerve impulse passes in one direction only; in efferent nerves from the center to the periphery, in afferent nerves from the periphery to the center. Experimentally, however, it can be demonstrated that when a nerve impulse is aroused in the course of a nerve by an adequate stimulus it travels equally well in both directions from the point of stimulation. When once started, the impulse is confined to the single fiber and does not diffuse itself to fibers adjacent to it in the same nerve-trunk.

Rapidity of Conduction of the Nerve Impulse.—The passage of a nerve impulse, either from the brain to the periphery or in the reverse direction, requires an appreciable period of time. The velocity with which the impulse travels in human sensory nerves has been estimated at about 50 meters a second, and for motor nerves at from 28 to 33 meters a second. The rate of movement is, however, somewhat modified by temperature, cold lessening and heat increasing the rapidity; it is also modified by electric conditions, by the action of drugs, the strength of the stimulus, etc. The rate of transmission through the spinal cord is considerably slower than in nerves, the average velocity for voluntary motor impulses being only 11 meters a second, for sensory impulses 12 meters, and for tactile impulses 40 meters a second.

Nerve Fatigue.—Inasmuch as nerves are parts of living cells, the seat of nutritive changes, it might be supposed that the passage of nerve impulses would be attended by the disruption of energy-holding compounds, the production of waste products, the liberation of heat, and in time by the phenomena of fatigue. Though it is probable that changes of this character occur, yet no reliable experimental data have been obtained which afford a clue as to the nature or extent of any such changes. Stimulation of motor nerves with the induced electric current for four hours appears to be without influence either on the intensity of the nerve impulse or the rate of its conduction.

Identity of Efferent and Afferent Nerves and Nerve Impulses.—Notwithstanding the classification of nerve-fibers based on differences of physiologic actions, there are no characters, either histologic or chemic, which serve to distinguish them from one another. Moreover, as the nerve impulse is conducted through a nerve-fiber equally well in both directions, as determined by experiments, it is probable that it does not differ in character in the two classes of nerves. That the efferent fibers conduct the nerve impulses from the nerve-centers to the periphery, and the afferent nerves from the periphery to the centers, is because of the fact that they receive their stimulus physiologically only in the centers or at the periphery. The fundamental reason for difference of effects produced by stimulation of different nerves is the character of the organ to which the nerve impulse is conducted. A nerve is merely the transmitter of the nerve impulse, which if conducted to a muscle excites contraction; to a gland, secretion; to a blood-vessel, variation in caliber; to special areas in the brain, sensations of light, sound, pain, etc.

Electric Excitation of Nerves.—For the purpose of studying the physiologic activities of nerves it has been found convenient to employ the nerve-muscle preparation (the gastrocnemius muscle and sciatic nerve) and to use as a stimulus the induced electric current. (See Fig. 52.) When kept moist, this preparation is extremely sensitive to either the galvanic or the induced current.

Though the development and conduction of a nerve impulse may be demonstrated by the deflection of the galvanometer needle or the movement of the mercury in the capillary electrometer, it is more conveniently demonstrated by the contraction of a muscle, the vigor of which, within limits, may be taken as a measure of the intensity of the impulse. The preparation should be enclosed in a moist chamber and the nerve connected with the inductorium through the intervention of non-polarizable electrodes. The muscle may be attached to the muscle-lever and its contractions recorded.

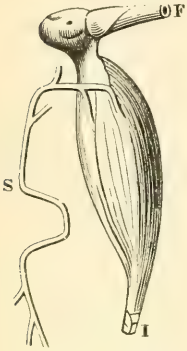

FIG. 52.—NERVE-MUSCLE PREPARATION OF A FROG. F. Femur. S. Sciatic nerve. I. Tendo Achillis. — (*Landois and Stirling.*)

A single shock of an induced current develops, it is believed, a single nerve impulse followed by a single muscle contraction. A minimal contraction following a minimal electric stimulus presupposes the development of a nerve impulse of low intensity. Within certain limits a maximal contraction following a maximal electric stimulus presupposes the development of a nerve impulse of high intensity. Intermediate contractions indicate nerve impulses of corresponding intensity.

Tetanization of a muscle indicates that the nerve impulses arrive at the muscle with a frequency so great that the muscle does not succeed in relaxing from the effect of one stimulus before the next arrives. Complete as well as incomplete tetanus may be developed by gradually increasing the frequency of the stimulus. The character of the contraction caused by indirect stimulation—*i. e.*, through the nerve—does not differ in any essential respect from that due to direct stimulation.

ELECTRIC PHENOMENA OF NERVES.

Electric Currents from Injured Nerves.—It was discovered by du Bois-Reymond that electric currents can be obtained from nerves as well as from muscles, and that the electric properties of the former correspond in most respects to those of the latter. The laws governing the development and mode of action of the currents derived from muscles are equally applicable to the currents derived from nerves.

A nerve-cylinder obtained by making two transverse sections of any given nerve presents, as in the case of muscles, a natural and two artificial transverse surfaces. A line drawn around the cylinder at a point lying midway between the two end surfaces constitutes the equator. From such a cylinder strong currents are obtained when the natural longitudinal surface and the transverse surface are connected with the electrodes of the galvanometer circuit. The strength of the current thus obtained will diminish or increase according as the electrode on the longitudinal surface is removed from or brought near to the equator. If two symmetric points on the longitudinal surface equidistant from the equator are united, no current is obtainable. When asymmetric points on the longitudinal surface are connected, weak currents are obtained, in which case the point lying nearer the equator becomes positive to the point more distant, which becomes negative. From these facts it is evident that all points on the longitudinal surface are electrically positive to the transverse surface and that the point of greatest positive tension is situated near the equator (Fig. 53).

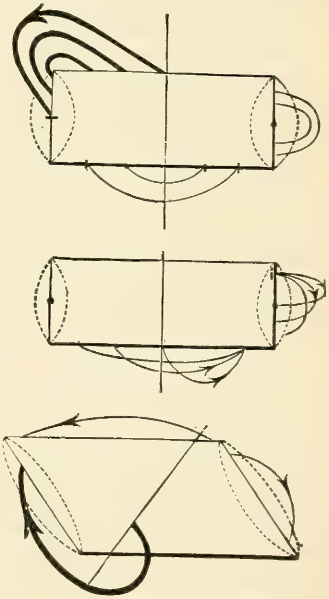

Fig. 53.—Diagram to Illustrate the Currents in Nerves. The arrowheads indicate the direction; the thickness of the lines indicates the strength of the currents. —(*Landois and Stirling.*)

The electromotive force of the nerve current varies in strength with the length and thickness of the nerve. The strongest current obtained from the nerve of the frog is equal to the 0.002 of a Daniell cell; that obtained from the nerve of the rabbit, 0.026 of a Daniell. The existence of the nerve current, its strength, duration, etc., depend largely on the maintenance of physiologic conditions. All influences which impair the nutrition of the nerve diminish the current. With the death of the nerve all electric phenomena disappear.

Negative Variation of the Nerve Current.—During the passage of the nerve impulse the resting nerve current, or the demarcation current, diminishes more or less completely in intensity, undergoes a *negative variation*, as shown by the return of the galvanometer needle, due to a change in its electromotive condition or to a diminution of the difference in potential between the positive longitudinal and negative transverse sections. This negative variation of the demarcation current is observed equally well from either the central or peripheral end of the nerve. If the two ends of the nerve are connected with galvanometers and the nerve stimulated in the middle, the demarcation currents simultaneously undergo a negative variation. This may be taken as a proof that the excitation process propagates itself equally well in both directions. The negative variation is intimately connected with changes in the molecular condition of the nerve and is not due to any extraneous electric or other influence. And du Bois-Reymond was also enabled to obtain a negative variation of the current in the nerves of a living frog which were yet in connection with the spinal cord. In this experiment the sciatic nerve was divided at the knee and freed from its connections up to the spinal column; the transverse and longitudinal surfaces were then placed in connection with the electrodes of the galvanometer wires and the current permitted to influence the needle. The animal was then subjected to the action of strychnin. Upon the appearance of the muscle spasms the needle was observed to swing backward toward the zero point to the extent of from 1 to 4 degrees, and upon the cessation of the spasms to return to its previous position. In an experiment of this nature it is obvious that the negative variation was the result of a physiologic stimulation of the nerve arising within the spinal cord.

The question also here arises as to whether the negative variation is due to a steady, continuous decrease of the natural current, or whether it is due to successive and rapidly following variations in its intensity, similar to that observed in muscles. Though this can not be demonstrated with the physiologic rheoscope, as was the case with the muscle, there can be no doubt, both from experimentation and analogy, that the latter supposition is the correct one. It has been shown that when non-polarizable electrodes connected with Siemen's telephone are placed in connection with the longitudinal and transverse sections of a nerve, low, sonorous vibrations are perceived during tetanic stimulation—a proof that the active state of the nerve is connected with the production of discontinuous electric currents. The oscillations of the mercurial column of the capillary electrometer also reveal similar electric changes. It was also demonstrated by Bernstein with a specially devised apparatus, the repeating rheotome, that the negative variation is composed of a large number of single variations which succeed each other in rapid succession and summarize themselves in their effect on the needle.

Electric Currents from Uninjured Nerves.—The pre-existence of electric currents in living and wholly uninjured nerves while at rest has also been denied by Hermann, who regards all portions of the nerve as isoelectric, any difference of potential being the result of some injury to its surface.

Action Currents.—For reasons to be stated below, it is very difficult to determine the presence of diphasic action currents during the passage of an excitatory impulse through the nerve-fiber. The so-called negative variation of the resting nerve current—the demarcation current—which is occasioned by tetanic stimulation, Hermann regards as the expression of an *action current* which flows in the nerve in a direction opposite to the demarcation current. The origin of this action current is to be sought for in the continuous negativity of that portion of the longitudinal surface of the nerve in contact with the diverting electrode, while the dying substance of the transverse surface takes no part in the excitation. This *tetanic* action current, or negative variation, was discovered by du Bois-Reymond, and Bernstein later succeeded in obtaining this action current during the passage of a single excitation process. That the return of the galvanometer needle toward the zero point is not due to an annulment of the demarcation current itself, but to the appearance of an action current, is shown by the fact that if the former be compensated by a battery current until the needle rests on the zero point the appearance of the latter current will cause the needle to swing in a direction the opposite of that caused by the demarcation current. The negative variation and action current may therefore be regarded as one and the same thing. It is the expression of the change the nerve is undergoing during the passage of the nerve impulse. The rapidity with which the negative variation or action current travels, the variation in its intensity from moment to moment, the time required for it to pass a given point, would express the change in the nerve to which the term nerve impulse is given. From experiments made with the differential rheotome, Bernstein calculated that the speed of the negative variation is about 28 meters a second; that it is at first feeble, soon rises to a maximum, and then declines; that it requires 0.0006 to 0.0008 of a second to pass a given point. From these data it is evident that the negative variation or action current has a space value of 0.0006 of 28 meters or about 18 mm. Transferring these statements to the nerve impulse, it may be said that it is a molecular disturbance, traveling at the rate of about 28 meters a second, is wave-like in character, the wave being 18 millimeters in length, and occupying from 0.0006 to 0.0008 of a second in passing any given point.

Absence of Diphasic Action Currents.—When any two points on the longitudinal surface which do not exhibit a current are connected with the galvanometer and a single wave of excitation passes beneath the electrodes, it might be expected that, as in the case of the muscle, a diphasic action current would be observed, from the fact that the portions of the nerve beneath the electrodes become alternately negative with reference to all the rest of the nerve. This, however, is not the case, the absence of the two opposing phases of the action current being explained on the supposition that the negativity of the two led-off points is of equal amount, and that, owing to the great rapidity with which the excitation wave travels, the two phases fall together too closely in time to alternately influence the galvanometer needle. During stimulation of the nerve, when two currentless or isoelectric points are connected, there is also an absence of the action current, as was observed first by du Bois-Reymond, and which is to be explained on similar grounds. It is true that an apparent action current is sometimes seen when the stimulating current is very powerful or the seat of stimulation too near the diverting electrodes. This, however, must be attributed to an electrotonic state of the nerve.

The Effects of a Galvanic Current on a Nerve.—When a constant galvanic current of medium strength is made to pass through a portion of a nerve, several distinct effects are produced:

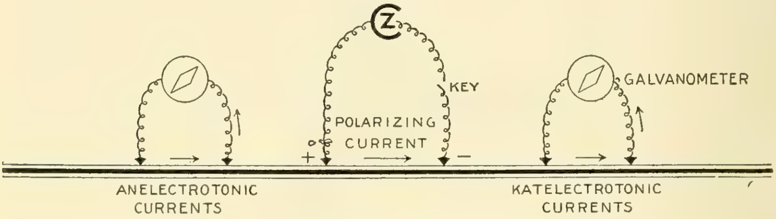

Fig. 54.—Electrotonic Currents.

1. *The development of a nerve impulse* at the moment the current enters and at the moment the current leaves the nerve, *i. e.*, at the moment the circuit is made and at the moment it is broken. The development of the nerve impulse is made evident by the contraction of the muscle if the nerve-muscle preparation be used. If the current be either very weak, or very strong, the muscle contraction may not always take place.

2. *The development of electric currents* on each side of the positive pole or anode, and the negative pole or kathode (see Fig. 54), which can be led off by means of wires into a galvanometer circuit from either the artificial transverse and longitudinal surfaces, or from any two points on the longitudinal surface as shown by the deflection of the galvanometer needle. The direction of these electric currents in the nerve coincides with that of the galvanic or "polarizing current." The "natural nerve currents," the currents of injury or demarcation currents, as they are variously termed, are at the same time increased and decreased at opposite extremities of the nerve according to the direction of the polarizing current.

To this changed condition of the electromotive forces in a nerve the term electrotonus was given (du Bois-Reymond). The currents themselves are known as electrotonic currents; from their relation to the anode and kathode, they are termed anelectrotonic and katelectrotonic currents. The condition of the nerve around the poles both in the intra-polar and extra-polar regions is known as anelectrotonus and katelectrotonus.

The electrotonic currents vary considerably in strength and extent, according to the intensity of the polarizing current, increasing steadily with the intensity of the latter up to the point at which the polarizing current begins to destroy the physical and chemic integrity of the nerve. The electrotonic currents are strongest in the immediate neighborhood of the electrodes, but gradually diminish in strength as the distance between the polarized and led-off portions is increased. The distance to which the electrotonic currents extend along the nerve will depend very largely upon the strength of the polarizing current, though it is conditioned by the physical state of the nerve; for if it be ligated or injured beyond the polarized portion, the electrotonic currents are abolished. The electrotonic currents have no necessary connection with the natural nerve currents, nor are they to be regarded as branchings of the galvanic current. They are in all probability of artificial origin, due to an inner positive and negative polarization of the nerve which extends for a variable distance on each side of the poles, and due to the action of the polarizing or the galvanic current.

3. *An alteration in the excitability and conductivity* of the nerve in the neighborhood of the poles, whereby the results of nerve stimulation—that is, muscle contraction, sensation, and inhibition—are increased or decreased according to the strength and direction of the current. To this condition the term electrotonus was also given (Pflüger). This word has thus been employed to express two distinct series of effects exhibited by a nerve through a portion of which a constant galvanic current is passing. It appears desirable, for the sake of clearness, to limit the term electrotonus to the electric or electrotonic currents which can be led off from either extremity of the nerve, and to apply to the modifications of irritability which accompany electrotonus the expression, electrotonic alteration of excitability and conductivity.

During the passage of the current the excitability of the intrapolar as well as the extra-polar regions undergoes a change which, as shown on examination, is found to be *diminished* in the neighborhood of the *anode* or positive pole and *increased* in the neighborhood of the *kathode* or negative pole. These alterations in the excitability are most marked in the immediate vicinity of the electrodes, though they extend for some distance into both the extra-polar and intra-polar regions, though with gradually diminishing intensity, until they finally disappear. Between the electrodes there is a point where the excitability is unchanged and known as the neutral or indifferent point (Fig. 55). The extent to which the excitability is modified as well as the position of the neutral point will depend largely on the strength of the polarizing or galvanic current.

The electrotonic alterations of excitability and conductivity can be experimentally demonstrated on the muscle-nerve preparation in the following manner:

1. With a descending current of medium strength. Previous to the closure of the polarizing current, the nerve is stimulated first in the extra-polar anodic region and the extra-polar kathodic region with an induction shock of medium intensity and the height of the contraction recorded. On repeating the stimulation *after* closure of the polarizing current the contraction resulting from stimulation of the anodic region will be enfeebled or may be entirely wanting, while the contraction from stimulation of the kathodic region will be decidedly increased. (See Fig. 56.)

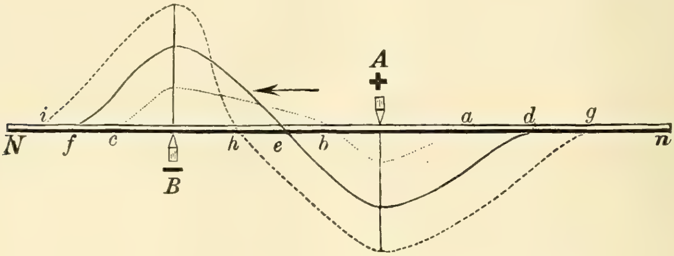

Fig. 55.—Scheme of the Electrotonic Excitability.—(*Landois and Stirling.*)

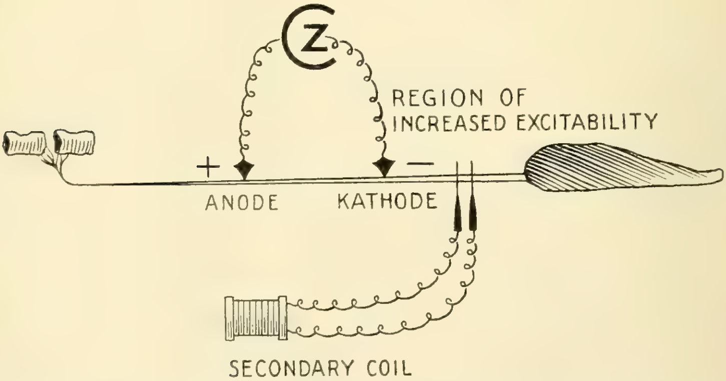

Fig. 56.—Diagram Showing the Region of Increased Excitability Caused by the Passage of a Galvanic Current, Stimulation of which Gives Rise to Increased Contraction.

2. With an ascending current of the same strength. After preliminary testing of the excitability and the subsequent closure of

the polarizing current, it will be found that stimulation of the extra-polar anodic region will provoke a much less energetic contraction or perhaps none at all. Stimulation of the extra-kathodic region, though of increased excitability, as shown by the previous experiment, may also fail to provoke a contraction, owing to the diminished conductivity of the region in the neighborhood of the anode. The impulse on reaching this region is blocked in its passage. A similar if not more marked decrease in the conductivity may be developed in the region of the kathode if the current strength be very great. (See Fig. 57.)

The Law of Contraction; Polar Stimulation.—It was stated in a previous paragraph that when a galvanic current of medium strength is made to enter a nerve, and when it is withdrawn from the nerve, there is a contraction of its related muscle. These are generally known as the make and break effects. During the actual passage of the current no effect is observed so long as its strength remains uniform. Any sudden variation in the strength of the current at once arouses the nerve to activity, as shown by a muscle contraction.

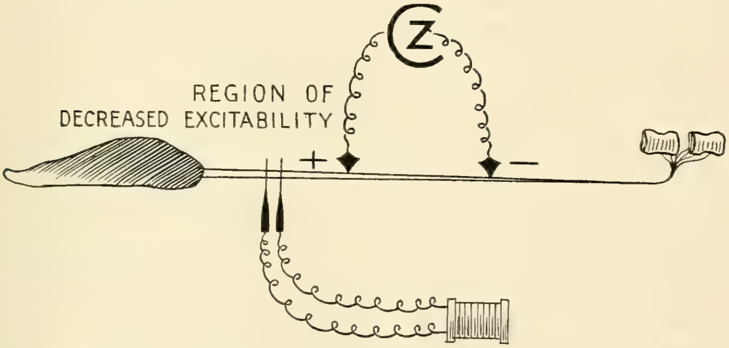

FIG. 57.—DIAGRAM SHOWING THE REGION OF DECREASED EXCITABILITY CAUSED BY THE PASSAGE OF A GALVANIC CURRENT, STIMULATION OF WHICH GIVES RISE TO DECREASED CONTRACTION.

The muscle response to the make and break of the constant current is more or less variable unless the direction of the current as well as its strength be taken into consideration. If the current is made to flow from the central toward the peripheral end of the nerve it is termed a *direct*, *descending*, or *centrifugal* current; if it is made to flow in the reverse direction, it is termed an *indirect*, *ascending*, or *centripetal* current. The strength of the current is determined and regulated by means of a rheocord.

The make and break of currents of different but known strengths and directions give rise to contractions which occur with more or less regularity. The order in which they occur under these varying conditions of experimentation has been determined and tabulated as follows by Pflüger, and is termed the *law of contraction:*

CURRENT INTENSITY.	ASCENDING CURRENT.		DESCENDING CURRENT.	
	Make.	Break.	Make.	Break.
Weak, ...	Contraction.	Rest.	Contraction.	Rest.
Medium, ...	Contraction.	Contraction.	Contraction.	Contraction.
Strong, ...	Rest.	Contraction.	Contraction.	Rest or weak contraction.

The results as above tabulated are sometimes complicated on the opening of the circuit by a series of irregular pulsations of the muscle, an apparent tetanus, and long known as the opening tetanus of Ritter, which is attributed to rapid changes in the irritability of the nerve, in the region of the anode. A similar tetanic contraction of the muscle is sometimes observed on the closure of the circuit due to continued excitation in the region of the kathode. This is known as the closing tetanus of Wundt or of Pflüger. All the phenomena of the law of contraction were explained by Pflüger on the assumption that the current stimulates the nerve only at the one electrode, at the *kathode on closing*, and at the *anode on opening;* or, in other words, by the appearance of katelectrotonus or by the disappearance of anelectrotonus, both conditions being attended by a rise of excitability—not, however, by the opposite changes. It is further assumed that the appearance of katelectrotonus is more effective as a stimulus than the disappearance of anelectrotonus. For these reasons the term *polar stimulation* is generally employed in discussing the make and break effects of the galvanic current. The law of contraction may then be explained as follows: Very feeble currents, either ascending or descending, produce contraction only upon the closure of the circuit, the sudden *increase of the excitability* in the *katelectrotonic area* being alone sufficient to generate an impulse. The contraction which follows the closing of the weak ascending current depends upon the fact that the decrease of excitability and conductivity at the anode is insufficient to interfere with the conduction of the kathodal stimulus. Medium currents, either ascending or descending, produce contraction both on closing and opening the circuit. The appearance of katelectrotonus and the disappearance of anelectrotonus are both sufficiently powerful to generate an impulse without, however, seriously impairing the conductivity of the nerve.

Very strong currents produce contraction only upon the opening of the ascending and closure of the descending currents, or upon the passage of the excitability in the former from the *marked anelectrotonic decrease to the normal condition*, and in the latter from the normal to that of katelectrotonic increase. The absence of contraction upon the closure of the ascending current is dependent upon the blocking of the kathodal stimulus by the decrease of the excitability and conductivity at the anode. With the opening of the descending current the disappearance of anelectrotonus should also be followed by contraction, which would indeed be the case if the stimulus so generated was not blocked by the decrease of the conductivity at the kathode in consequence of the fall of a high state of katelectrotonus to the normal condition.

The order in which the contractions occur may be tabulated as follows:

	With Ascending Current.		With Descending Current.	
Weak, ...1.	K. C. C.*	..	K. C. C.	..
Medium, ...2.	K. C. C.	A. O. C.†	K. C. C.	A. O. C.
Strong, ...3.	..	A. O. C.	K. C. C.	A. O. C.(?)

Polar Stimulation of Human Nerves.—The preceding statements as to changes in the excitability caused by the passage of a constant current, as well as to the law of contraction, are based entirely on experiments made with the isolated nerve of the frog. It is probable, however, that the same phenomena would have been observed had the nerve of a mammal been used and its excitability been maintained.

If the electrodes connected with the wires of a sufficiently strong galvanic battery be applied to the skin over the course of a superficially lying nerve, *e. g.*, the brachial, it will be found that there occurs on the closure of the circuit an *increase* in the excitability in the extra-polar anelectrotonic region and a *decrease* in the excitability in the extra-polar katelectrotonic region, as shown by stimulating the nerve in the extra-polar regions with the induced current—results which are in apparent contradiction to those obtained with the isolated nerve. This want of accordance in the results of the two classes of experiments arises from a failure to recognize the fact that the physiologic anode and kathode do not coincide with the physical anode and kathode.

It has been experimentally demonstrated that owing to the large amount of readily conducting tissue by which the nerve is surrounded, the current density, though great immediately under the electrode, quickly decreases at a short distance from it, so that for the nerve it becomes almost *nil*. The current, therefore, shortly after entering, again leaves the nerve at various points which become physiologic kathodes. Stimulation of this physiologic kathode with the induced current gives rise, therefore, to the phenomenon of increased excitability in the region of the anode. If, however, the galvanic and stimulating current be combined in one circuit and both be applied to the same tract of nerve, results will be obtained which harmonize with those obtained with the frog's nerve.

The changes in the excitability of a nerve of a living man and the contractions which follow the closing and opening of the constant current have been thoroughly studied by Waller and de Watteville. These observers employed a method similar to that of Erb, conjoining in one circuit the testing and polarizing currents. By the graphic method they recorded first the contraction produced by an induction shock alone; and, secondly, the contraction produced by the same stimulus under the influence of the polarizing current. As a result of many experiments, they also demonstrated an increase of the excitability in the polar region when it is cathodic, and a decrease when it is anodic. Following the suggestion of Helmholtz, that the current density quickly decreases with the distance from the electrodes, they recognize, at the point of entrance and exit of the current from the nerve, two regions—a polar, having the same sign as the electrode, and a peripolar, having the opposite sign (Figs. 58 and 59).

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* K. C. C., kathodal closing contraction. † A. O. C., anodal opening contraction.

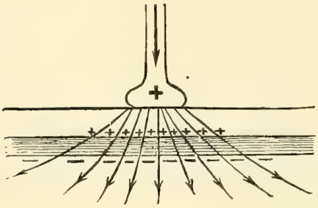

FIG. 58.—ANODE OF BATTERY. Polar region of nerve is anodic. Peripolar region of nerve is cathodic.

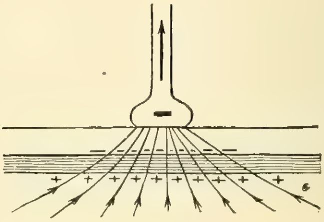

FIG. 59.—CATHODE OF BATTERY. Polar region of nerve is cathodic. Peripolar region of nerve is anodic.—(*Waller.*)

The peripolar regions also experience similar alterations of excitability, though less in degree, according as they are kathodic or anodic.

As it is impossible to confine the current to the trunk of the nerve when surrounded by living tissues, as is easily the case when experimenting with the frog's nerves, it is incorrect to speak of either ascending or descending currents. Waller,* who has thoroughly studied the electrotonic effects of the galvanic current from this point of view, sums up his conclusions in the following words: "We must apply one electrode only to the nerve and attend to its effects alone, completing the circuit through a second electrode, which is applied according to convenience to some other part of the body.

"Confining our attention to the first electrode, let us see what will happen according as it is *anode* or *kathode* of a galvanic current (Figs. 58 and 59). If this electrode be the anode of a current, the latter enters the nerve by a series of points and leaves it by a second series of points; the former, or proximal series of points, collectively constitutes the *polar* zone or region; the latter, or distal series of points, collectively constitutes the *peripolar* zone or region. In such case the polar region is the seat of entrance of current into the nerve—

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* "Human Physiology," p. 363, 1891.

i. e., is *anodic;* the peripolar region is the seat of exit of current from the nerve—*i. e.*, is *kathodic.* If, on the contrary, the electrode under observation be the kathode of a current, the latter enters the nerve by a series of points which collectively constitute a 'peripolar' region, and it leaves the nerve by a series of points which collectively constitute a 'polar' region. The current, at its entrance into the body, diffuses widely, and at its exit it concentrates; its 'density' is greatest close to the electrode, and, the greater the distance of any point from the electrode, the less the current density at that point; hence it is obvious that the current density is greater in the polar than in the peripolar region. These conditions having been recognized, we may apply to them the principles learned by study of frogs' nerves under simpler conditions.

"Seeing that, with either pole of the battery, whether anode or kathode, the nerve has in each case points of entrance (constituting a collective anode) and points of exit to the current (constituting a collective kathode), and admitting as proved that make excitation is kathodic, break excitation anodic, we may, with a sufficiently strong current, expect to obtain a contraction at make and at break with either anode or kathode applied to the nerve; and we do so, in fact. When the kathode is applied, and the current is made and broken, we obtain a *kathodic make contraction* and a *kathodic break contraction;* when the anode is applied, and the current is made and broken, we obtain an *anodic make contraction* and an *anodic break contraction.* These four contractions are, however, of very different strengths; the kathodic make contraction is by far the strongest; the kathodic break contraction is by far the weakest; the kathodic make contraction is stronger than the anodic make contraction; the anodic break contraction is stronger than the kathodic break contraction. Or, otherwise regarded, if, instead of comparing the contractions obtained with a sufficiently strong current, we observe the order of their appearance with currents gradually increased from weak to strong, we shall find that the kathodic make contraction appears first, that the kathodic break contraction appears last, and the formula of contraction for man reads as follows:

"Weak current, ...	K. C. C.			
Medium current, . .	K. C. C.	A. C. C.	A. O. C.	
Strong current, . . .	K. C. C.	A. C. C.	A. O. C.	K. O. C."

The constant or the galvanic current is frequently used for therapeutic and diagnostic purposes. In accordance with the statements above quoted, one electrode should be applied to the part to be investigated, the other to some indifferent region. The electrode conveying the current to or from this part should be of a size sufficient to localize the current and to increase its density. It was discovered by Duchenne that there are certain points all over the body stimulation of which is more quickly followed by muscle contraction than others. It was subsequently discovered by Remak that these points coincide with the entrance of the nerve into the muscle. It is to these motor points that the one electrode should be applied. The position of some of these points on the forearm is shown in Fig. 60.

Reactions of Degeneration.—In consequence of the degeneration and changes in irritability which occur in nerves when separated from their centers and in muscles when separated from their related nerves, either experimentally or as the result of disease, the response of these structures to the induced, and the make and break of the constant current, differs from that observed in the physiologic condition. The facts observed under the application of these two forms of electricity are of importance in the diagnosis and therapeutics of the precedent lesions. The principal difference of behavior is observed in the muscles, which exhibit diminished or abolished excitability to the induced current, while at the same time manifesting an increased excitability to the constant current; so much so is this the case that a closing contraction is just as likely to occur at the positive as at the negative pole. This peculiarity of the muscle response is termed the *reaction of degeneration.* The synchronous diminished excitability of the nerves is the same for either current. The term "partial reaction of degeneration" is used when there is a normal reaction of the nerves, with the degenerative reaction of the muscles. This condition is observed in progressive muscular atrophy.

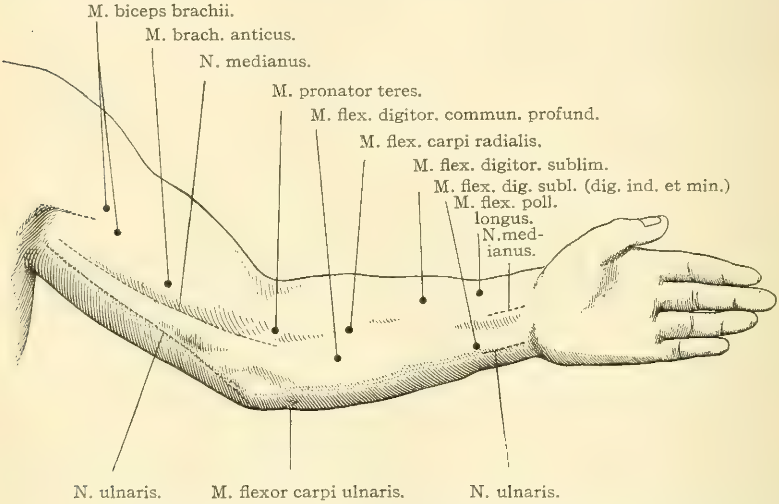
M. biceps brachii.
M. brach. anticus.
N. medianus.
M. pronator teres.
M. flex. digitor. commun. profund.
M. flex. carpi radialis.
M. flex. digitor. sublim.
M. flex. dig. subl. (dig. ind. et min.)
M. flex. poll. longus.
N. medianus.
N. ulnaris.
M. flexor carpi ulnaris.
N. ulnaris.

FIG. 60.—MOTOR POINTS OF THE MEDIAN AND ULNAR NERVES, WITH THE MUSCLES SUPPLIED BY THEM.—(*Landois and Stirling.*)

Reflex Action.—Inasmuch as many of the muscle movements of the body, as well as the formation and discharge of secretions from glands, variations in the caliber of blood-vessels, inhibition and acceleration in the activity of various organs, are the result of stimulations of the terminal organs of afferent nerves, they are termed, for convenience, reflex actions, and, as they take place for the most part through the spinal cord and medulla oblongata and independently of the brain or of volitional influences, they are also termed involuntary actions. A reflex action of skeletal muscles, glands, or non-striated muscles of blood-vessels or of viscera, therefore, may be defined as an action which takes place independent of volition and in response to peripheral stimulation. As many of the processes to be described in succeeding chapters are of this character, requiring for their performance the coöperation of several organs and tissues associated through the intermediation of the nerve system, it seems advisable to consider briefly, in this connection, the parts involved in a reflex action, as well as their mode of action. As shown in Fig. 61, the necessary structures are as follows:

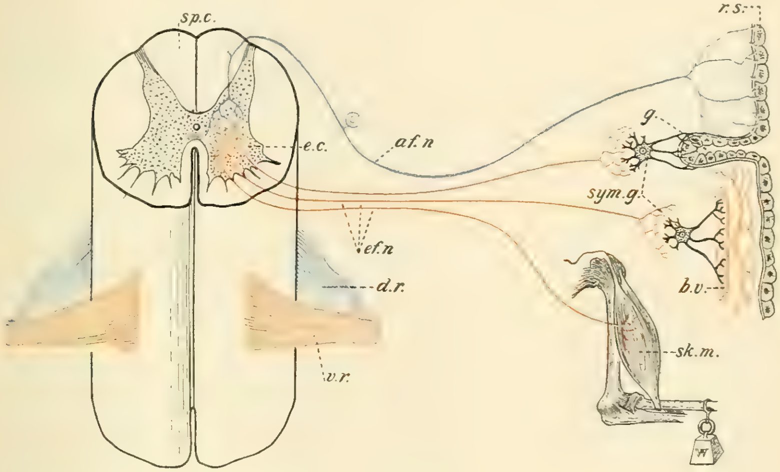

Fig. 61.—Diagpam Showing the Structures Involved in the Production of Reflex Actions. (*G. Bachman.*) *r.s.* Receptive surface; *af.n.* afferent nerve; *e.c.* emissive or motor cells in the anterior horn of the gray matter of the spinal cord, *sp.c.*; *ef. n.* efferent nerves distributed to responsive organs, *e.g.*, directly to skeletal muscles, *sk.n.*, and indirectly through the intermediation of sympathetic ganglia, *sym. g.*, to blood-vessels, *b.v.*, and to glands, *g.* The nerves distributed to viscera are not represented.

1. A receptive surface, skin, mucous membrane, sense-organ, etc.
2. An afferent nerve-fiber and cell.
3. An emissive cell, from which arises—
4. An efferent nerve, distributed to a responsive organ, as
5. Skeletal muscle, gland, blood-vessel, etc.

Such a combination of structures constitutes a reflex mechanism or arc, the nerve portion of which, in the case of skeletal muscles, is composed of but two neurons—an afferent and an efferent. In the case of glands and non-striated muscles, whether of blood-vessels or viscera, the efferent neuron instead of passing direct to the responsive organ, arborizes around the nerve-cells of a peripheral sympathetic ganglion. The reflex arc is then continued by the processes of the ganglion cells. An arc of this simplicity would of necessity subserve but a simple movement. The majority of reflex activities, however, are extremely complex, and involve the coöperation and coördination of a number of nerve centers situated at different levels of the spinal cord on the same and opposite side, and of responsive organs frequently situated at distances more or less remote from one another. This implies that a number of neurons are associated in function. The transference of nerve impulses coming from a localized area of a sentient surface to emissive cells situated at different levels is accomplished by the intercalation of a third neuron situated in the gray matter which is in connection, on the one hand, with the central terminals of the afferent neuron, and, on the other hand, through its collateral branches with the dendrites of the efferent neurons situated at different levels of the cord. (Fig. 62.)

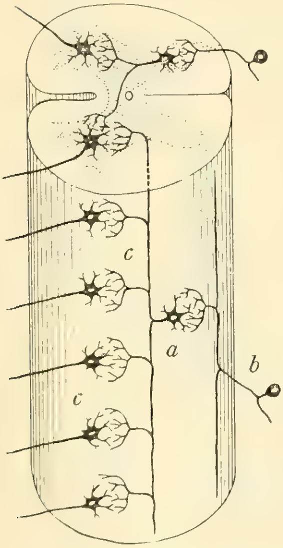

Fig. 62.—Diagram Showing the Relation of the Third Neuron *a*, to the Afferent Neuron *b*, and to the Efferent Neurons *c*, *c*, *c*.—(*After Kölliker.*)

For the excitation of a reflex action it is essential that the stimulus applied to the sentient surface be of an intensity sufficient to develop in the terminals of the afferent nerve a series of nerve impulses, which, traveling inward, will be distributed to and received by the dendrites of the emissive or motor cell. With the reception of these impulses there is apparently a disturbance of the equilibrium of its molecules, a liberation of energy, and, in consequence, a transmission outward of impulses through the efferent nerve to muscle, gland, or blood-vessel, separately or collectively, with the production of muscle contraction, a secretion, vascular dilatation or contraction, etc. The reflex actions take place, for the most part, through the spinal cord and medulla oblongata, which, by virtue of their contained centers, coördinate the various organs and tissues concerned in the performance of the organic functions. The movements of mastication; the secretion of saliva; the muscle, gland, and vascular phenomena of gastric and intestinal digestion; the vascular and respiratory movements; the mechanism of micturition, etc., are illustrations of reflex activity.

CHAPTER IX.

FOODS.

The functional activity of every organ and tissue of the body is accompanied by a more or less active disintegration of the living material, the bioplasm, of which it is composed, as well as of the food materials circulating in its interstices. The complex molecules of the living material and of the non-living food materials are continually undergoing disruption and falling into less complex and more stable compounds; these, through oxidative processes, are eventually reduced through a series of descending chemic stages to a small number of simpler compounds which, being of no further value to the organism, are eliminated by the various eliminating or excretory organs, the lungs, skin, kidney, and liver. Among these excreted compounds derived from tissue and from food metabolism the more important are urea, uric acid, and carbon dioxid. Many other compounds, organic as well as inorganic, are also eliminated from the body in the various excretions, though they are present in but small amounts. Coincident with this metabolic process there is a transformation of potential into kinetic energy, which manifests itself for the most part as heat and mechanic motion.

In order that the organs and tissues may continue in the performance of their functions, it is essential that they be supplied with nutritive materials similar to those which enter into their own composition: viz., proteids, fat, carbohydrates, water, and inorganic salts. These compounds, though originally derived from the food, are immediately derived from the blood as it flows through the capillary blood-vessels. The blood is therefore to be regarded as a reservoir of nutritive material in a condition to be absorbed and transformed into utilizable and living material. Inasmuch as the materials lost to the body daily, through disintegration and oxidation, though considerable, are supplied by the blood, it is evident that this fluid would diminish rapidly in volume, with a corresponding decline in functional activity, were it not restored by the introduction into the body of new material in the food. With the diminution of the volume of the blood and an insufficient supply to the tissues, there arise the sensations of hunger and thirst, which lead to the consumption of food and the subsequent restoration of the physiologic condition of the tissues. These two sensations are also partially dependent on the empty condition of the stomach and the dryness of the mucous membrane of the mouth and throat.

The foods which are consumed daily in response to the sensations of hunger and thirst are complex in composition and contain, though in varying amounts, proteins, fats, carbohydrates, water and inorganic salts, which, in contradistinction to foods, are termed food principles or nutritive principles. In these compounds is also to be found the potential energy necessary to maintain the dynamic equilibrium of the body and which will become manifest as heat and mechanic motion in the transformations of the material underlying the nutritive processes.

The animal body may be therefore regarded as a machine capable each day of performing a certain amount of work by the expenditure of a definite amount of energy. In the performance of its work, whether it be the raising of weights against gravity, the overcoming of friction, cohesion, or elasticity, the machine suffers disintegration and metabolizes a portion of the food materials and loses a portion of its available energy. Unlike other machines, however, it possesses the power, within limits, of self-renewal, self-adjustment, when supplied with foods in proper quantity and quality.

QUANTITIES OF FOOD PRINCIPLES REQUIRED DAILY.

In order that the body may continue in the performance of its work and yet retain a given weight, it is essential that the loss to the body daily shall be exactly compensated by the introduction and assimilation of a corresponding amount of food principles. If this condition is realized, the body neither gains nor loses, but remains in a condition of nutritive equilibrium. The determination of the exact quantities of the different food principles required daily and their ratio one to another is made from an examination of the quantity and composition of the daily excretions. Since the proteins disintegrated are represented in the excretions by urea and similar nitrogen-holding compounds and the fats and carbohydrates by carbon dioxid, it becomes possible to determine from them the quantities required to restore equilibrium under any given condition. But as the activity of the nutritive changes will vary in accordance with climatic conditions, work done, etc., and as the excreted products will vary in the same ratio, it is obvious that the required amounts of food will vary in accordance with these varying conditions, if equilibrium is to be maintained.

Various estimates have been made by different investigators as to the amounts of the excreted products and the food principles required daily, which, though differing to some extent, have, nevertheless, an average nutritive and energy-producing value. The following table shows the diet scale of Vierordt and the excretions to which it would give rise. As the income and outgo practically balance, there would be no change in the weight.

COMPARISON OF THE INCOME AND OUTGO.

Income.	Grams.	Ounces.	Outgo.	Grams.	Ounces.
Protein,	120	4.25	Water,	2818	99.30
Fat.	90	3.17	Urea,	40	1.40
Carbohydrates,	330	11.64	Feces, dry,	38	1.60
Salts,	32	1.13	Salts,	32	1.13
Water,	2818	99.30	Carbon dioxid,	922	32.37
Oxygen,	756	26.66	Water formed in body,	296	10.33
	4146	146.13		4146	146.15

Other estimates as to the amounts of the organic food principles required daily are as follows:

	Ranke. Grams.	Voit. Grams.	Moleschott. Grams.	Atwater. Grams.	Hultgren. Grams.
Protein,	100	118	130	125	134
Fat,	100	56	84	125	79
Starch,	250	500	550	400	522

In arranging tables showing the relation between the income and the outgo, it is generally customary to state merely the amounts by weight of the nitrogen and carbon each contains. This method furnishes sufficiently accurate information regarding the metabolism of the body, for the reason that the nitrogen represents the protein, and the carbon, with the exception of that contained in the protein, the fat and carbohydrates which have undergone disintegration or metabolism.

The following balance table, as given by Ranke, shows the relation of the nitrogen to the carbon in the average mixed diet and in the excretions of a man weighing 70 kilograms, in a condition of nutritive equilibrium:

Income.	Grams.	N.	C.
Protein,	100	15.5	53.0
Fat,	100	....	79.0
Carbohydrates,	250	....	93.0
		15.5	225.0
Outgo.	**Grams.**	**N.**	**C.**
Urea,	31.5	14.4	6.16
Uric acid,	0.5		
Feces,	....	1.1	10.84
CO_2,	....	....	208.00
		15.5	225.00

From the above it will be observed that the daily discharge for each kilogram of body-weight is 0.21 gram nitrogen and 3.03 grams of carbon; the relation of the two being $\frac{C}{N}=14.5$. On a diet in which there is an excess of either proteid or carbohydrates this ratio necessarily changes.

CLASSIFICATION OF FOOD PRINCIPLES.

Though the food principles are grouped as proteids, fats, carbohydrates, etc., the members of each group differ somewhat in chemic composition, digestibility, and nutritive value. These groups are as follows:

1. PROTEINS.

Principle.	Where found.
Myosin,	Flesh of animals.
Albumin, vitellin,	White of egg, yolk of egg.
Caseinogen,	Milk.
Serum-albumin, fibrin,	Blood contained in meat.
Glutin,	Grain of wheat and some other cereals.
Vegetable albumin,	Soft-growing vegetables.
Legumin,	Peas, beans, lentils, etc.

2. FATS.

Animal fats,	In adipose tissue of animals.
Vegetable oils,	In seeds, grains, nuts, fruits, and other vegetable tissues.

3. CARBOHYDRATES.

Dextrose or grape-sugar,	In fruits.
Levulose or fruit-sugar,	
Lactose or milk-sugar,	Milk.
Saccharose or cane-sugar,	Sugar-cane, beet roots.
Maltose,	Malt and malted foods.
Starch,	Cereals, tuberous roots, and leguminous plants.
Glycogen,	Liver, muscles.

4. INORGANIC.

Water,	In nearly all animal and vegetable foods.
Sodium and potassium chlorid,	
Sodium, potassium, and calcium phosphates and carbonates,	
Iron,	

5. VEGETABLE ACIDS.

Citric, tartaric, acetic, malic,	In fruit and vegetables.

6. ACCESSORY FOODS.

Coffee, Tea, Cocoa, Alcohol.

Disposition of Food.—The *protein* principles of the food, after undergoing all those changes which are embraced under the term digestion, are absorbed from the intestine. During the act of absorption they are transformed into the forms of protein characteristic of blood. After being distributed by the blood-stream to the tissues, they are brought into relation with the living cells. The disposition made of the protein material by the bioplasm of the cell has not been definitely determined. According to Voit, of the protein thus brought into contact with the living tissues, only a small percentage is utilized and assimilated for tissue repair. This he terms tissue or organ protein. The remaining large percentage circulating in the interstices of the tissues, though not forming an integral part of them, is acted on directly by them, merely in virtue of contact—split up, oxidized, and reduced to simpler compounds. This he terms circulating protein.

According to Pflüger and others, this view is not tenable. Pflüger asserts that, as material changes or metabolism can only take place within living cells, all the protein must first be assimilated and organized by the cells before it can undergo metabolic changes. Metabolism by contact action is denied, and the division of proteins into organ and circulating protein is not justifiable.

In the process of metabolism the protein suffers disintegration, giving rise through oxidation to some carbon-holding compound, possibly fat, and to some nitrogen-holding compounds, which eventually give rise to urea. The intermediate stages, however, are not definitely known; the immediate antecedents of urea are probably carbamate and carbonate of ammonia. The disintegration of the proteins is attended by the disengagement of heat, thus contributing to the general store of the energy of the body.

The *fat* principles, after digestion, are absorbed by the lymphatic vessels and discharged by the thoracic duct into the blood, from which they rapidly disappear. Though it is possible that a portion of the fat enters directly into the formation of the living material, it is generally believed that it is at once oxidized and reduced to carbon dioxid and water with the liberation of energy. The natural supposition that a portion of the ingested fat was directly stored up in the cells of the areolar connective tissue, thus giving rise to adipose tissue, has been a subject of much controversy, though modern experimentation renders this very probable. The body-fat, under physiologic conditions, is also a product of the metabolic activity of connective-tissue cells and is a derivative of both proteids and carbohydrates.

The *carbohydrate* principles, after digestion, are absorbed into the blood as dextrose. This compound is then stored up in the liver and muscles as glycogen. The intermediate stages which glycogen passes through before it is reduced to carbon dioxid and water are only imperfectly known. Though a large part of the carbohydrate material is at once oxidized, it is now well established that another portion contributes to the formation of, if it is not directly converted into, fat. As the carbohydrates form a large portion of the food, they contribute materially to the production of energy.

The *inorganic* principles, though not playing apparently as active a part in the metabolism of the body as the organic, are nevertheless essential to its physiologic activity.

Water is promptly absorbed after ingestion and becomes a part of the circulating fluids—blood and lymph. In the digestive apparatus it favors the occurrence of those chemic changes in the food necessary for their absorption, it promotes absorption of the food, holds various constituents of the blood and other fluids in solution, hastens the general metabolism of the body, holds in solution various products of metabolic activity, and, leaving the body through the excretory organs, promotes their elimination.

Sodium chlorid is absorbed into the blood and, unless taken in excess, is utilized in replacing that which is lost to the organism daily. The exact rôle which sodium chlorid plays in the nutritive process is unknown; but, as it is present as a necessary constituent in all the fluids and solids of the body, and as it is instinctively employed as a condiment, it may be assumed to have a more or less important function.

When taken as a condiment, it imparts sapidity to the food and excites the flow of the digestive fluids; it ultimately furnishes the chlorin for the hydrochloric acid of the gastric juice. Judging from the impairment of the nutrition as observed in animals after deprivation of salt for a long period of time, if favorably influences the growth and functional activity of all tissues.

It is well known that herbivorous animals, races of men as well as individuals who live largely on vegetable foods, require a larger additional amount of sodium chlorid than carnivorous animals, or human beings who live largely on animal foods, even though the two classes of foods contain relatively the same amounts. The explanation is that the vegetable foods contain potassium salts which, meeting in the blood with sodium chlorid, undergo decomposition into potassium chlorid and sodium carbonate or phosphate, all of which, when in excess, are at once eliminated by the kidneys. The blood, therefore, becomes poorer in sodium chlorid, one of its necessary constituents.

Potassium phosphate and *carbonate* are also essential to the normal composition of the solids and fluids. They impart a certain degree of alkalinity to the blood and lymph, one of the conditions necessary to the life and activity of the tissue-cells bathed by them. When administered in small doses, they increase the force of the heart, raise the arterial pressure, and increase the activity of the circulation.

Calcium phosphate and *carbonate* are partly utilized in maintaining the solidity of the bones and teeth, replacing the amount metabolized daily. Inasmuch as the metabolism of these two tissues is slight, there is not much need in the adult for lime as an article of food. In young animals lime is essential to the solidification and development of bone. When deprived of it, the skeleton undergoes a defective development similar to the pathologic condition known as rickets. Lime is present in milk to the extent of 0.15 per cent., as well as in eggs and peas in relatively large quantities.

Iron is contained in both animal and vegetable foods, not, however, in the form of inorganic iron, nor in the form of an organic salt, but as a compound with nuclein, thus forming an integral part of the proteid molecule. After absorption the iron is utilized in the formation of the coloring-matter of the blood-corpuscles—hemoglobin. The organic compounds of iron and the nucleins have been termed *hematogens*. The amount of iron ingested has been estimated at from 10 to 90 milligrams, the larger part of which is eliminated in the feces. The relatively small part eliminated by the kidneys and liver is usually taken as the amount metabolized, though it is probable that this is not wholly true, as there is evidence that iron can be retained in the body and utilized again in the formation of new hemoglobin. Contrary to what might be expected, milk contains but a very small quantity of iron, not more than 3 or 4 milligrams in 1000 grams (human milk)—an amount insufficient for the development of the necessary hemoglobin. This is compensated for, however, by the accumulation of iron in the liver during intrauterine life. According to Bunge, the liver of a newly born rabbit contains as much as 18.2 milligrams per 100 grams of body-weight, while at the end of twenty-four days it only contains 3.2 milligrams per 100 grams of body-weight.

Vegetable acids increase the secretions of the alimentary canal, and are apt, in large amounts, to produce flatulence and diarrhea. After entering into combination with bases to form salts, they stimulate the action of the kidneys and promote a greater elimination of all the urinary constituents. In some unknown way they influence nutrition; when deprived of these acids, the individual becomes scorbutic.

The *accessory* foods—coffee, tea, and cocoa—when taken in moderation have a stimulating influence on the nervous system, as shown by the removal of both mental and physical fatigue, by an increased capacity for sustained mental work, by the persistent wakefulness among those unaccustomed to their use. Coffee more especially increases the frequency and force of the heart-beat, raises the arterial pressure, and hastens the general blood-flow. It has no influence either in the way of increasing or decreasing proteid metabolism.

Tea frequently acts as an astringent on the alimentary canal on account of the tannin which passes into the water when the infusion is made. Inasmuch as tannin also coagulates peptones, the excessive use of tea as a beverage is apt to derange the digestive organs and the general process of digestion.

Cocoa is more nutritive than either coffee or tea, on account of the large amount of fat and proteid it contains. It is, however, less stimulating.

The active principles in coffee, tea, and cocoa, and to which their effects are to be attributed, are *caffein*, *thein*, and *theobromin* respectively. These alkaloids are chemically closely related one to the other and to the compound xanthin. They are present in the coffee seeds, the tea leaves, and the cocoa bean to the extent of 1.7 per cent., 1.4 per cent., and 1.6 per cent. respectively. When prepared as a beverage, however, there is three times as much caffein in coffee as thein in tea.

Alcohol when taken in small quantities stimulates the digestive glands to increased activity and thus promotes digestive power. Its absorption into the blood is followed by increased action of the heart, dilatation of the cutaneous blood-vessels, a sensation of warmth, and an excitation of the brain. In large quantities it acts as a paralyzant, depressing more especially the vaso-constrictor nerve-centers and certain areas of the brain, as shown by an impairment in the power of sustained attention, clearness of judgment, and muscle coördination.

Alcohol is undoubtedly oxidized in the body, as only about 2 per cent. can be obtained from the urine and expired air. It thus contributes to the store of the body-energy. As to whether for this reason it can be regarded as a food—that is, whether it can be substituted in part at least for fat or carbohydrate material without impairing the proteid metabolism—is at present a subject of experimentation and discussion. According to some investigators, alcohol does not retard proteid metabolism, for when it is introduced into the body in amounts equivalent to the carbohydrates withdrawn from the food there is at once a rise in the amount of nitrogen excreted. Hence it cannot be regarded as a food. According to other investigators, alcohol retards or protects proteid metabolism just as effectually as an equivalent amount of starch or sugar. Many more experiments are required to decide this question. When taken habitually in large quantities, alcohol deranges the activities of the digestive organs, lowers the body temperature, impairs muscle power, lessens the resistance to depressing external conditions, diminishes the capacity for sustained mental work, and leads to the development of structural changes in the connective tissues of the brain, spinal cord, and other organs. In zymotic diseases and in cases of depression of the vital powers it is most useful as a restorative agent.

THE ENERGY OR HEAT VALUE OF FOOD PRINCIPLES.

The food consumed not only restores the material metabolized and discharged from the body, but also the energy which has been expended as heat and mechanic motion. The food principles are products of the constructive processes taking place in the vegetable world during the period of growth and activity. At the time of their formation there is an absorption and storing of the sun's energy which then exists in a potential condition. During the metabolism of the animal body these compounds are reduced through oxidation to relatively simple bodies, such as carbon dioxid, water, urea, etc., with the liberation of their contained energy. All of the energy of the body, whatever its manifestations may be, can be traced to chemic changes going on in the tissues, and more particularly to those changes involved in the oxidation of the food principles.

The amount of heat or energy which any given food principle will yield can be determined by burning a definite amount (*e. g.*, 1 gram) to carbon dioxid and water and ascertaining the extent to which the heat thus liberated will raise the temperature of a given amount of water (*e. g.*, 1 kilogram). The amount of heat may be expressed in gram or kilogram degrees or calories, a gram calorie or kilogram calorie being the amount of heat required to raise the temperature of a gram or a kilogram (1000 grams) of water 1° C. The apparatus employed for this purpose is termed a calorimeter, and consists essentially of a closed chamber in which the oxidation takes place, surrounded by a water jacket, the rise in temperature of the water indicating the amount of heat produced.

The results obtained by investigators employing different calorimeters and different food principles of the same group vary, though within certain limits: *e. g.*, 1 gram of casein yields 5.867 kilogram calories; 1 gram of lean beef, 5.656 calories; 1 gram of fat yields 9.353, 9.423, 9.686 calories; 1 gram of carbohydrate, 4.182, 4.479, etc., calories. These numbers represent the physical heat values of these food principles.

In the human body as determined by calorimetric methods the oxidation of the food principles yields practically the same amount of heat they yield when oxidized outside the body, with the exception of the proteins, which are oxidized only to the stage of urea. As this compound is capable of further reduction in the calorimeter to carbon dioxid and water with the liberation of heat, the quantity of heat it contains must therefore be deducted from the calorimetric heat value of the protein. According to Rubner, 1 gram of urea will yield 2.523 kilogram calories. As the urea which results from the oxidation of 1 gram of protein is about $\frac{1}{3}$ of a gram, the amount of heat to be deducted from the heat value of the protein is $\frac{1}{3}$ of 2.523, or 0.841 calories. It has also been shown that some of the ingested protein escapes in the feces, the heat value of which must also be determined and deducted. This having been done, the *physiologic* heat value becomes 4.124 calories.

The following estimates give approximately the number of kilogram calories produced when the food is burned to carbon dioxid, water, and urea in the body:

1 gram of protein yields,	4.124	calories.
1 " " fat "	9.353	"
1 " " carbohydrate yields,	4.116	"

The total number of kilogram calories or kilogram degrees of heat yielded by any of the previously given diet scales can be readily determined by multiplying the quantities of food principles consumed by the above-mentioned factors. The diet scale of Vierordt, for example, yields the following:

120 grams of protein yields,	494.88	calories.
90 " " fat "	841.77	"
330 " " starch "	1358.28	"
	2694.93	

The total calories obtained from other diet scales would be as follows: Ranke, 2335; Voit, 3387; Moleschott, 2984; Atwater, 3331; Hultgren, 3436.

Starvation.—The relation of the different food principles to the general nutritive process becomes more apparent from an examination of the excretions from the body during the process of starvation combined with an examination of the organs and tissues after death. If an animal be deprived entirely of food, a decline in body-weight at once sets in, which continues until about 40 per cent. of the weight has been lost, when death generally ensues. This results from the fact that the active tissue cells consume, for the purpose of maintaining the normal temperature of the body, not only their own reserve food material, but that of the less active or storage tissues as well; and, in consequence, there is a progressive diminution in weight.

The phenomena which characterize this non-physiologic condition are as follows: hunger, intense thirst, gastric and intestinal uneasiness and pain, diminished pulse-rate, and respiration, muscular weakness and emaciation, a lessening in the amount of urine and its constituents, diminished exhalation of carbon dioxid, an exhalation of a fetid odor from the body, vertigo, stupor, delirium, at times convulsions, a sudden fall in body-temperature, and finally death. The duration of life after complete deprivation of food varies from eight to thirteen days or more, though this period can be prolonged if the animal be supplied with water, this being more essential under the circumstances than the organic materials which can be supplied by the organism itself. The duration of the starvation period will vary in accordance with the previous condition of the animal and the amount of reserved food the body contains. The excretion of urea declines very rapidly during the first two days—a fact which has been attributed to a rapid consumation of the surplus proteid food. After this period, when the tissues begin to metabolize their own proteid, the excretion remains fairly constant until toward the close, when the amount eliminated falls very rapidly. As proteids contain about 16 per cent. of nitrogen, 1 part of nitrogen equals 6.25 parts of protein. Hence, for every 1 gram of nitrogen or 2.14 grams urea excreted, it may be assumed that 6.25 grams of protein or, according to Voit, 30 grams of flesh have been metabolized. The daily excretion of urea, therefore, indicates the extent of the protein metabolism.

It has been observed also that there is a steady diminution in the excretion of carbon dioxid, though this is greatest in the last few days. As fat contains about 76 per cent. of carbon, 1 part of carbon equals 1.31 parts of fat. Hence, for every 1 gram of carbon or 3.66 grams carbon dioxid excreted it may be assumed that 1.31 grams of fat have been metabolized. The daily excretion of carbon, therefore, indicates the extent of fat metabolism. The carbohydrates are here left out of consideration, as they constitute only about 1 per cent. of the body-weight. It must be borne in mind, however, that in the metabolism of protein a certain quantity of fat is produced which also undergoes oxidation. The amount of the carbon or the fat that the protein would give rise to, as previously determined, must therefore be subtracted from that eliminated by the lungs, etc., in order to determine the amount of body-fat metabolized. Observations of human beings in the fasting condition show that for a period of ten days there is a daily excretion of about 21 grams of urea, equivalent to about 70 grams of protein. This amount, however, may be reduced to from 50 to 60 per cent. if the individual has a surplus of body-fat. Human beings under similar circumstances may lose during the first few days 200 grams of fat daily.

The following table shows the excretion of nitrogen and carbon and the calculated amounts of protein and fat metabolized from an experiment made by Ranke on himself during a fast of twenty-hours, beginning twenty-four hours after the last meal:

Disintegration of Tissue. (Calculated.)			Expenditure.		
	Nitrogen.	Carbon.		Nitrogen.	Carbon.
Protein, 50 gm., ...	7.8	26.5	Urea, 17 gm., ... Uric acid, 0.2 gm., ...	7.2	3.4
Fat, 199.6 gm., ...	0.0	157.5	Carbon dioxid, ...	0.0	180.6
	7.8	184.0		7.2	184.0

Coincidently with these losses to the body there is also a gradual loss of inorganic salts, and toward the termination of the period a sudden fall in temperature of several degrees centigrade, in consequence of the final consumption of all available foods, when death ensues, in all probability, from a cessation in the action of the heart.

Post-mortem Appearances.—It has been experimentally determined that animals die when the body-weight has declined to about 40 per cent. Post-mortem examination shows that the loss of material, though very generally distributed throughout the body, is greatest in organs and tissues least essential to life.

The results of an analysis of the organs and tissues of a cat after a thirteen-day period of starvation, during which the animal lost 1017 grams in weight, are given in the following table, based on data furnished by Voit:

Organ.	Percentage.	Actual Loss of Tissue.
		Grams.
Adipose tissue,	97	267
Spleen,	67	6
Liver,	54	49
Testes,	40	1
Muscles,	31	429
Blood,	27	37
Kidneys,	26	7
Skin and hair,	21	89
Lungs,	18	3
Intestines,	18	21
Pancreas,	17	1
Bones,	14	55
Heart,	3	0
Nervous system,	3	1

It will be observed from this table that the adipose tissue suffers the greatest loss, the entire amount disappearing with the exception of a small portion in the posterior part of the orbital cavity and around the kidneys. The muscles, though only losing 31 per cent. of their weight, yet furnish 429 grams of presumably proteid material, for nutritive purposes. The heart and nervous system experience but slight loss.

Mixed Diet.—The chemic composition of the tissues, taken in connection with their metabolism during starvation, implies that no one article of food is sufficient for tissue repair and heat production; but that all classes of foods—in other words, a mixed diet—are essential to the maintenance of a normal nutrition. Experimental investigation has also conclusively established this fact. Moreover, the amounts of nitrogen and carbon eliminated daily, and the ratio existing between them, indicate the amounts of proteid, fat, and carbohydrate which are required to cover the loss.

Metabolism on a Purely Protein Diet.—Notwithstanding the chemic composition of the proteins and the possibility of their giving rise to both fat and a carbohydrate during their metabolism it has been found extremely difficult to maintain the normal nutrition for any length of time on a pure protein or fat-free flesh diet. This, however, has been accomplished with dogs. It was found, however, that, in order to maintain the equilibrium, it was necessary to increase the proteins from two to three times the usual amount. Thus, a dog weighing 30 to 35 kilograms required from 1500 to 1800 grams of flesh daily in order to get the requisite amount of carbon to prevent consumption of its own adipose tissue. Under similar circumstances, a human being weighing 70 kilograms would require more than 2000 grams of lean beef—an amount which, from the nature of the digestive apparatus, it would be practically impossible to digest and assimilate for any length of time. Even the slight habitual excess beyond the amount normally required is imperfectly assimilated and gives rise to the production of nitrogen-holding compounds which, on account of the difficulty with which they are eliminated by the kidneys, accumulate within the body and develop the gouty diathesis, with all its protean manifestations.

Metabolism on a Fat and Carbohydrate Diet.—As nitrogen is an indispensable constituent of the tissues, it is evident that neither fat nor carbohydrates can maintain nutritive equilibrium except for very short periods. On such a diet the tissues consume their own proteids, as shown by the continuous excretion of urea, though the amount is less than during starvation. An excess of fat retards the metabolism of proteids. The same holds true for the carbohydrates.

Thus, in any well-arranged dietary there should be a combination of proteins, fats, and carbohydrates in amounts sufficient to maintain nutritive equilibrium; in other words, to repair the loss of tissue and to furnish the requisite amount of heat in accordance with work done, as well as with climatic and seasonal variations.

COMPOSITION OF FOODS.

The food principles essential to the maintenance of the nutrition of the body are contained in varying proportions in compound substances termed foods; *e. g.*, meat, milk, wheat, potatoes, etc. Their nutritive value depends partly on the amounts of their contained food principles and partly on their digestibility. The dietary of civilized man embraces foods derived from both the animal and vegetable worlds.

Composition of Animal Foods.—The following table shows the average percentage composition of various kinds of meats, cow's milk, and eggs:

In 100 Parts	Beef.	Veal.	Mutton.	Pork.	Fowl.	Fish.	Cow's Milk.	Eggs.
Water,	76.25	77.82	75.59	72.57	70.80	79.30	86.87	73.67
Protein,	20.24	19.86	17.11	19.31	22.70	18.30	4.75	12.55
Fat,	1.68	0.82	5.47	5.82	4.10	0.70	3.50	12.11
Carbohydrates,	0.50	0.80	0.60	0.60	1.20	0.90	4.00	0.55
Salts,	1.38	0.70	1.23	1.70	1.20	0.80	0.17	1.13

Meats.—It will be observed from these analyses that the meats contain from 18 to 20 per cent. of a protein which belongs in virtue of its chemic relations to the group of globulins. In the living condition this body, known as myosinogen, is in a semifluid condition, but shortly after death undergoes coagulation, giving rise to solid myosin and a soluble albumin. There are also present in meat small percentages of other forms of protein; *e. g.*, myoalbumin, myoglobulin, paramyosinogen, etc. After being subjected to the cooking process, meats contain the albuminoid body gelatin, a product of the transformation of the proteids of the connective tissue.

The percentage of fat, contained within the meat substance, is very small except in mutton and pork, where it rises to 5.4 per cent. and 5.8 per cent. respectively. The fat-globules in these meats are packed closely between the muscle-fibers, and prevent the easy entrance of the digestive fluids, and hence they are more difficult of digestion than beef.

The carbohydrates vary from 0.5 to 1 per cent., and are represented by glycogen. The principal inorganic salts are potassium phosphate and sodium chlorid.

Cooking, when properly done, not only makes the meat more palatable and appetizing from the development of agreeable flavors, but converts the connective tissue, which, in old animals especially, is tough and resisting, into gelatin, thus rendering it more easy of mastication and digestion. At the same time parasitic organisms, such as the embyronic forms of tenia or tapeworm, trichina spiralis, as well as bacterial growths, which frequently infest the bodies of animals, are destroyed and made harmless.

Milk is the natural food of the young of all mammals, and is usually regarded as typical on account of the ratio existing among its nutritive principles. The analysis given above is that of cow's milk. Examined microscopically, milk is seen to consist of a clear fluid, the milk plasma, holding in suspension an enormous number of small, highly refractive oil-globules, which measure on the average about $\frac{1}{10000}$ of an inch in diameter. Each globule is supposed by some observers to be surrounded by a thin albuminous envelope, which enables it to maintain the discrete form. Others deny the existence of such a membrane. The chief protein constituent of milk, caseinogen, is held in solution by the presence of phosphate of lime. On the addition of acetic acid or sodium chlorid up to the point of saturation the caseinogen is *precipitated* as such and may be collected by appropriate chemic methods. When taken into the stomach, caseinogen is *coagulated;* that is, it is separated into casein or tyrein and a small quantity of a new soluble proteid. This change is brought about by the presence in the gastric juice of a special ferment known as rennin or pexin.

The fat of milk is more or less solid at ordinary temperatures. It is a combination of olein, palmitin, and stearin, with a small quantity of butyrin and caproin. When milk is allowed to stand for some time, the fat-globules rise to the surface and form a thick layer known as cream. When subjected to the churning process, fat-globules run together and form a coherent mass—butter.

Lactose is the particular form of sugar found in milk. In the presence of Bacillus acidi lactici, the lactose is decomposed into lactic acid and carbon dioxid, the former of which not only imparts a sour taste to the milk, but causes a *precipitation* of the caseinogen. The chief salt found in milk is phosphate of lime, and this is the chief source of this agent in the formation of bones.

Eggs are also to be regarded as complete natural foods, inasmuch as they contain all the necessary food principles. The analysis given in the above table represents the composition of the entire egg. The white of the egg contains 12 per cent. of proteid and 2 per cent. of fat. The yolk, however, contains 15 per cent. of proteid and 30 per cent. of fat.

Composition of Cereal Foods.—The average composition of the principal cereals is shown in the following table:

In 100 Parts.	Wheat.	Rye.	Barley.	Oats.	Corn.	Rice.	Buck-wheat.
Water,	13.56	12.65	13.77	12.37	13.10	13.12	12.62
Protein,	12.35	12.55	11.14	10.41	9.85	7.88	10.02
Fat,	1.75	1.97	2.16	5.23	4.57	0.85	2.24
Carbohydrate,	67.90	67.95	64.93	57.78	68.42	76.55	64.43
Cellulose,	2.63	3.00	5.31	11.19	2.50	0.55	8.67
Salts,	1.81	1.88	2.69	3.02	1.56	1.05	2.02

That the cereals are most important and useful articles of diet is evident from their composition, consisting, as they do, of proteins and carbohydrates in large proportion. Owing to the cellulose or woody fiber which envelops and penetrates the grain, they are somewhat difficult of digestion. A section of a grain of wheat shows the external cellulose envelope, the husk, beneath which is a layer of large cells containing the chief protein—the gluten. The interior of the grain consists of small cavities, the walls of which are formed of cellulose and which contain the granules of starch, fat, small quantities of proteid, and inorganic salts. All other cereals have a similar structure.

In the preparation of white flour from wheat it is customary to remove the husk, a process which involves the removal also of a portion, if not all, of the gluten cells, so that such flour contains less nitrogenized material than the original grain. It is possible, however, in the milling of wheat, to remove only the husk and retain the gluten in the flour, as in the preparation of whole wheat flour.

Bread is an artificially prepared food made either of wheat or rye. Owing to the fact that the proteids of the other cereals do not possess the same adhesive properties when kneaded with water, they can not be used for bread-making purposes. In the making of bread, the flour is kneaded with water until a glutinous mass—dough—is formed. During this process, salt, sugar, and yeast are added. It is then placed in a temperature of about 100° F. In the presence of heat and moisture the natural ferment of the flour—diastase—converts a portion of the starch into sugar, which in turn is split up into carbon dioxid and alcohol by the yeast plant. The bubbles of carbon dioxid, becoming entangled in the dough, cause it to swell or rise and subsequently give the porous or spongy character to the bread. When baked at a temperature of 400° F., the alcohol is driven off; yeast cells and other organisms are destroyed; the starch, particularly that on the surface, is dextrinized. Thus prepared, white bread consists of water, 32 per cent.; protein, 8.8 per cent.; fat, 1.7 per cent.; carbohydrate, 56.3 per cent.; salts, 0.9 per cent. The principal salts are potassium and magnesium phosphate. Whole wheat bread consists of water, 40 per cent.; protein, 12.2 per cent.; fat, 1.2 per cent.; carbohydrate, 43.5 per cent.; salts, 1.3 per cent.; cellulose, 1.8 per cent.

Composition of Vegetable Foods.—The average composition of some of the principal vegetables is shown in the following table:

In 100 Parts.	Beans.	Peas.	Potatoes.	Beets.	Turnips.	Tomatoes.	Asparagus.	Cabbage.
Water,	13.74	14.99	75.47	82.20	89.42	96.30	93.75	89.97
Protein,	23.21	22.85	1.95	1.80	1.35	0.90	1.79	1.89
Fat,	2.14	1.79	0.15	0.30	0.18	0.50	0.25	0.20
Carbohydrates,	53.67	52.36	20.69	13.00	7.36	2.80	2.63	4.87
Cellulose,	3.69	5.43	0.76	..	0.94	..	1.04	1.84
Salts,	3.55	2.58	0.98	1.60	0.75	0.40	0.54	1.23

The vegetable foods, as a class, vary considerably in nutritive value and digestibility, the latter depending on the amount of cellulose they contain. A section of a vegetable shows not only the presence of an external cellulose envelope, but also an inner framework which penetrates its substance in all directions. The nutritive principles are contained in small cavities, the walls of which are formed by the framework. Nearly all vegetables require cooking before being eaten. When subjected to heat and moisture, not only is the texture of the vegetable softened and disintegrated, but the starch grains are hydrated and partially prepared for conversion into dextrin and sugar. At the same time various savory substances are set free, which make the food more palatable.

Beans and **peas** contain large quantities of a proteid, legumin, and starch, and hence are especially valuable as nutritive foods. The presence of the cellulose envelope, especially in ripe beans and peas, combined with rather a dense texture, renders them somewhat difficult of digestion. **Potatoes,** though largely employed as food, are extremely poor in protein, 2 per cent., and carbohydrates, 20 per cent. When sufficiently cooked they are easily digested, owing to the small amount of cellulose they contain.

Green vegetables,—*e. g.*, lettuce, spinach, tomatoes, asparagus, onions, etc., though containing food principles in small amounts, are, nevertheless, valuable adjuncts to the dietary, for the reason that they contain inorganic as well as organic salts, which appear to be necessary to the maintenance of the normal nutrition. The want of green vegetables has been supposed to be the cause of scurvy.

Ripe fruits, grapes, cherries, apples, pears, peaches, strawberries, lemons, oranges, etc., though consumed largely, possess but little nutritive value. They consist largely of water, 75 to 85 per cent., proteins a trace, sugar from 5 to 13 per cent., organic acids (citric, malic, tartaric), pectose, and various inorganic salts.

Relative Value of Animal and Vegetable Foods.—Though both animal and vegetable foods contain the different classes of food principles, it is not a matter of entire indifference as to which are consumed. It has been found by experiment that animal proteids are more easily and completely digested and absorbed than vegetable proteids; that cellulose is not only highly indigestible, but by its presence in large quantities retards the digestive process and impairs the activity of the entire digestive mechanism, though in moderate quantity it undoubtedly aids digeston indirectly by mechanically promoting peristalsis. The following table shows the relative digestibility of the two classes of foods:

Weight of Food.	Vegetable.		Animal.	
	Digested.	Undigested.	Digested.	Undigested.
Of 100 parts of solids, ...	75.5	24.5	89.9	11.1
Of 100 parts of protein, ...	46.6	53.4	81.2	18.8
Of 100 parts of fats or carbohydrates.	90.3	9.7	96.9	3.1

Construction of Dietaries.—Inasmuch as neither animal nor vegetable foods contain the food principles in proper quantities and proportions, the instinctive choice of mankind has led to a combination of the two classes of foods. From the analyses tabulated above it becomes comparatively easy to construct a suitable dietary, composed of different articles of food, in which the food principles shall bear the proper ratio one to the other—a ratio based on the total quantity of nitrogen (15 to 20 grams) and carbon (225 to 300 grams) eliminated from the body daily.

It is only necessary, therefore, to combine two or more foods, the composition of which is known, in quantities sufficient to furnish the requisite amount of nitrogen and carbon, or their equivalents in proteid, fat, and carbohydrates. As illustrations of such combinations the following examples are given:

Foods.			Food Principles.		N.	C.
Meat, ...	250 gm.,	8.8 oz.	Protein, ...	100 gm.	15	50
Bread, ...	400 gm.,	14.2 oz.				
Fat, ...	100 gm.,	3.5 oz.	Fat, ...	100 gm.	..	75
Sugar, ...	70 gm.,	2.5 oz.	Carbohydrates, ...	250 gm.	..	100
					15	225

Foods.		N.	C.
Meat,	225 gm., ½ lb.	7.5 gm.	34 gm.
Bread,	450 gm., 1 lb.	5.5 gm.	117 gm.
Fats,	113 gm., ¼ lb.	...	84 gm.
Potatoes,	450 gm., 1 lb.	1.3 gm.	45 gm.
Milk,	225 gm., ½ pint	1.7 gm.	20 gm.
Eggs,	113 gm., ¼ lb.	2.0 gm.	15 gm.
Cheese,	56 gm., ⅓ lb.	3.0 gm.	20 gm.
		21.0	335

Waller.

DAILY RATION OF THE UNITED STATES SOLDIER.

Fresh beef,	20 oz.
or pork,	12 oz.
or bacon,	12 oz.
Flour,	18 oz.
or soft bread,	18 oz.
or hard bread,	16 oz.
Potatoes,	16 oz.
or potatoes 11⅕ and tomatoes 4⅕	16 oz.
Beans or peas,	2.4 oz.
Rice or hominy,	1.6 oz.
Coffee,	1.6 oz.
Sugar,	2.00 oz.
Vinegar,	0.32 gill
Salt,	0.60 gill

CHAPTER X.

DIGESTION.

Foods are heterogeneous compounds consisting of organic and inorganic nutritive principles associated with a varying amount of non-nutritive material, such as the dense parts of the connective tissue of the animal foods and the woody fiber or cellulose of the vegetable foods. Before the nutritive principles can be utilized they must be dissociated from the non-nutritive material. Even when consumed in the free state, the food principles are seldom in a condition to be absorbed into the blood and assimilated by the tissues. When foods are consumed in their natural state or after they have been subjected to the cooking process, they are subjected while in the food canal to the solvent action of various fluids by which they are disintegrated and reduced to the liquid condition. The nutritive principles freed from their combinations are changed in chemic composition and transformed into substances capable of absorption. To all the physical and chemic changes which foods undergo in the food canal the term digestion has been given.

The **digestive apparatus** comprises the entire alimentary or food canal and its various appendages: the teeth, the tongue, the mouth, the gastric and intestinal glands, the pancreas, and the liver (Fig. 63).

The canal itself is a musculo-membranous tube about thirty-two feet in length, and extends from the mouth to the anus. It may be subdivided into several distinct portions, as mouth, pharynx, esophagus, stomach, small and large intestines. The mouth is provided (1) with teeth, by which the food is divided, (2) with the tongue, and (3) with glands, by which a solvent fluid, the saliva, is secreted. The glands, though situated for the most part outside the mouth, are connected with it by means of ducts. Posteriorly the mouth opens into the pharynx or throat, a somewhat pyramidal-shaped structure about five inches in length, which in turn is followed by the esophagus or gullet, a tube about nine inches in length. As the esophagus passes through the diaphragm it expands into the stomach, a curved pyriform organ, which serves as a reservoir for the reception and retention of the food for a varying length of time. The small intestine is that portion of the alimentary canal extending from the end of the stomach to the beginning of the large intestine; owing to its length, about twenty-two feet, it presents a very convoluted appearance in the abdominal cavity. Embedded in its walls are the intestinal glands which open on its surface and secrete the intestinal fluid. In the upper portion of the small intestine, within five inches of the stomach, there are generally two orifices, the terminations of the ducts of the liver and pancreas, organs which secrete the bile and pancreatic juice respectively. The large intestine is from five to six feet in length and extends from the end of the small intestine to the anus. Its walls contain a large number of glands.

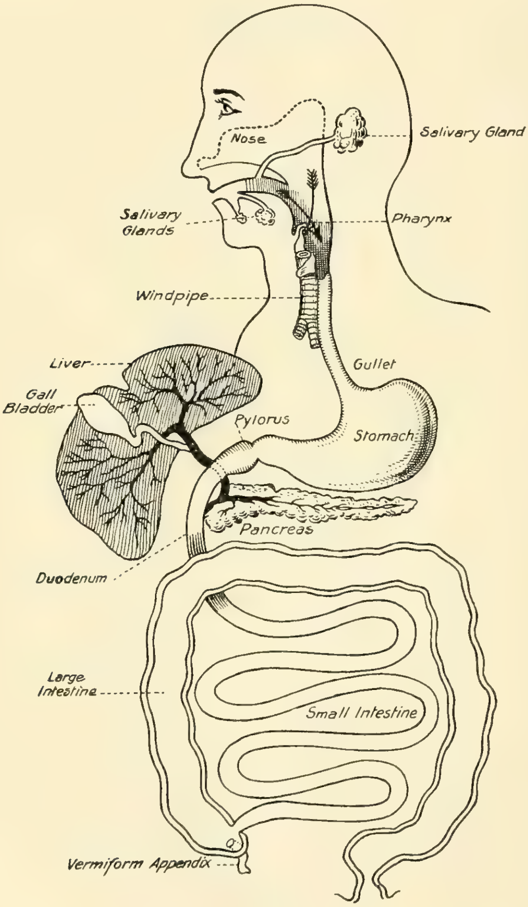
Nose
Salivary Gland
Salivary Glands
Pharynx
Windpipe
Liver
Gall Bladder
Gullet
Pylorus
Stomach
Pancreas
Duodenum
Large Intestine
Small Intestine
Vermiform Appendix

FIG. 63.—DIAGRAM OF THE ALIMENTARY CANAL.—(*Modified from Landois.*)

The general process of digestion is largely accomplished by the chemic action of the digestive fluids: the saliva, the gastric, intestinal, and pancreatic juices, and the bile. Though taking place throughout a large portion of the food canal, the process may be subdivided into several stages: viz., mouth digestion, gastric digestion, and intestinal digestion.

As a result of the action of these fluids the nutritive principles are prepared for absorption into the blood; the non-nutritive principles, along with certain waste products, pass into the large intestine to be finally extruded from the body.

MOUTH DIGESTION.

The digestion of the food as it takes place in the mouth comprises a series of physical and chemic changes, the result of the action of the teeth, the tongue, and the saliva. The mechanic division of the food and the incorporation of the saliva with it are termed respectively mastication and insalivation.

MASTICATION.

Mastication is the mechanic division of the food, and is accomplished by the teeth and the movements of the lower jaw under the influence of muscle contractions. Complete mechanic disintegration of the food is essential to its subsequent solution and chemic transformation; for when finely divided it presents a larger surface to the action of the digestive fluids and thus enables them to exert their respective actions more effectively and in a shorter period of time.

The Teeth.—In man passing from childhood to adult life two sets of teeth make their appearance. The first set constitute the temporary, deciduous, or milk teeth; the second set constitute the permanent teeth, which should last with proper care through life or to an advanced age.

The temporary teeth, twenty in number, ten in each jaw, though smaller than the permanent teeth, have the same general conformation. They are divided into four incisors, two cuspids or canines, and four molars for each jaw.

The permanent teeth, thirty-two in number, sixteen in each jaw, are divided into four incisors, two cuspids or canines, four bicuspids or premolars, and six molars for each jaw.

Each tooth may be said to consist of three portions: (1) the crown, or that portion which projects above the gums; (2) the root or fang, that portion embedded in the alveolar socket; (3) the constricted portion or neck, which is surrounded by the free margin of the gum. The teeth are firmly secured in their sockets by a fibrous membrane, the peridental membrane, which is attached, on the one hand, to the alveolar process, and, on the other, to the cementum.

A vertical section of a tooth shows that it consists of three distinct solid structures, the enamel, the dentine, and the cementum, which have the anatomic relationship as represented in Fig. 64. In the center of the dentine there is a cavity the general shape of which varies in different teeth, and which is occupied during the living condition by the tooth pulp.

Microscopic examination of the tooth reveals the presence of irregular stellate spaces, the interglobular spaces, between the dentine and the cementum, which are occupied by connective-tissue cells. Clefts of varying size are also observed at the junction of the dentine and the enamel, and which extend for some distance into the latter.

The *enamel* is composed of dense hard cylinders which, on account of their small size and close relationship, appear to be hexagonal in shape. These cylinders are held together by cement substance. The free border of the enamel is covered, in early life at least, by a thin membrane known as the cuticle or membrane of Nasmyth.

The *dentine* is somewhat less dense than the enamel. It is composed of connective-tissue fibers embedded in a ground-substance, both of which have undergone calcification in the course of development. The dentine is penetrated by a series of fine canals, the dentine canals or tubules, which begin by open mouths on the pulp side. From this point the tubules pass outward to the cementum and enamel, where their terminal branches communicate with and terminate in the interglobular spaces and clefts. In their course the tubules give off a series of branches which communicate freely with one another. The dentine bordering the tubule is somewhat more dense than the intertubular portion and constitutes what is known as the dentinal sheath or Neumann's sheath.

The *cementum* resembles bone because it contains both lacunæ and canaliculi, though it is, as a rule, devoid of Haversian canals.

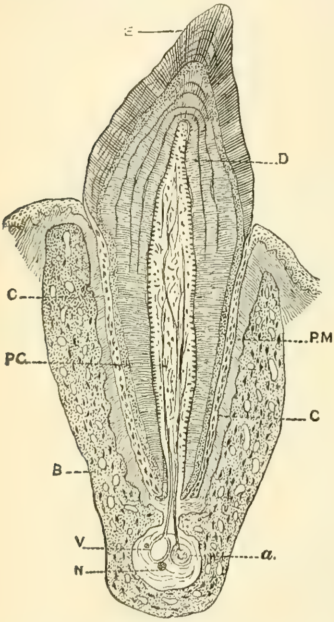

Fig. 64.—Vertical Section of Tooth in Jaw. *E.* Enamel. *D.* Dentine. P. M. Periodontal membrane. *P.C.* Pulp cavity. *C.* Cement. *B.* Bone of lower jaw. *V.* Vein. *a.* Artery. *N.* Nerve.—(*Stirling.*)

The *pulp* consists of a framework of connective tissue which affords support to blood-vessels and nerves, both of which enter the pulp chamber through a small foramen at the apex of the root. The outer surface of the pulp is covered with a layer of large spheric cells, the odontoblasts. Each cell presents on its inner surface short processes which pass into the pulp; on its outer surface it presents a long process which enters a dentine tubule and extends as far as its ultimate terminations. Collectively these processes are known as the dentine fibers. Inasmuch as the fibers do not completely occupy the lumen of the tubule, it is probable that there is a free circulation of lymph from the pulp chamber through the dentine tubules into the enamel clefts, into the interglobular spaces, and possibly into the lacunæ of the cementum.

The *peridental membrane* is composed of connective-tissue fibers abundantly supplied with blood-vessels, and nerves.

Movements of the Lower Jaw.—The lower jaw is capable of a downward and upward, an antero-posterior, and a lateral movement, all dependent on the peculiar construction of the—

Temporo-maxillary Articulation.—This articulation is formed by the anterior portion of the glenoid cavity, the eminentia articularis and the condyle of the inferior maxilla, all of which are united by means of ligaments. Situated between the glenoid cavity and the condyle is a plate of fibro-cartilage oval in shape and biconcave. This cartilage divides the joint into two cavities—one above, the other below—each of which is provided with a synovial membrane. The function of the cartilage is to present constantly an articulating surface to the condyle in the various movements of the lower jaw, which it is enabled to do by virtue of its mobility.

In the downward movement of the lower jaw each condyle glides forward, carrying with it the interarticular fibro-cartilage the upper concave surface of which is applied to the convex surface of the eminentia articularis. In the upward movement of the jaw both the condyles and the cartilages pass backward and resume their normal position. The movements of depression and elevation are made possible by the transverse direction of the condyle. In the carnivorous animals, whose food requires considerable cutting, these movements are especially well developed. In the antero-posterior movement the jaw moves in a horizontal direction and the condyles and the articular cartilages glide forward and backward in the glenoid fossæ. In the rodent animals the long axis of the condyle runs in the antero-posterior direction, which allows of a considerable gliding movement. When the jaw performs a lateral movement, the condyle and cartilage of one side remain in their normal position, while the opposite condyle and cartilage glide forward in the glenoid fossa, directing the symphysis of the jaw to the opposite side of the median line. The lateral movements are well exhibited by the herbivorous animals, in which they are quite extensive, and made possible by the small size of the condyle and the large extent of articulating surface. In man the structure of the joint is such as to admit of all these possibilities, and the lower jaw acquires in consequence great freedom of movement.

The Functions of the Muscles of Mastication.—The movements of the lower jaw are caused by the action of numerous muscles, which, having a fixed point of origin, are attached to various points on its surface. The muscles concerned in the movements of mastication are presented in the following table:

Anterior belly of digastic Mylohyoid Geniohyoid	Depress the lower jaw and open the mouth.
Temporal Internal portion of masseter Internal pterygoid	Elevate the lower jaw and close the mouth.
External pterygoids External portion of masseter Anterior fibers of temporal	Draw the lower jaw forward and cause the lower teeth to project beyond the upper.
Posterior fibers of temporal Internal portion of masseter Digastric, mylohyoid, and geniohyoid	Draw the lower jaw back to its normal position.
Internal pterygoids External pterygoids	Contracting alternately, draw the jaw to the opposite side.
Pterygoids, external and internal Temporal Masseter	Produce grinding movements of the lower jaw.

The action of the depressor muscles becomes apparent when their points of origin and insertion are considered. The anterior belly of the digastric, the mylohyoid, the geniohyoid muscles, agree in having a similarity of origin—the hyoid bone—and a common area of insertion, the anterior portion of the inferior maxillary. Their anatomic relation is such that their combined action will depress the lower jaw and open the mouth.

The elevator muscles arise from various points on the side of the head, and are inserted into the coronoid process, ramus, and internal surface of the angle of the lower jaw. When the mouth has been opened, the simultaneous contraction of these muscles elevates the jaw and closes the mouth with considerable force. The power of these muscles is very great, and depends on the shortness and thickness of the muscle-bundles.

The action of the rotator muscles, those which give rise to the lateral movements of the jaw, depends in like manner on their origin and insertion. Arising from the superior maxillary and sphenoid bones, they are inserted into the neck of the condyle and angle of the lower jaw respectively. When they contract, the condyle on the corresponding side is drawn forward, while the opposite condyle remains stationary. As a result, the symphysis of the jaw is directed to the opposite side. The grinding movements of the jaw are produced by the coördinated action of all the groups of muscles acting more or less successively.

For the proper mastication of the food it is essential that it be kept between the opposing surfaces of the teeth. This is accomplished by the contraction of the orbicularis oris and buccinator muscles from without and the tongue muscles from within.

The Nerve Mechanism of Mastication.*—The movements of mastication, though originating in efforts of the will and under its control, are for the most part of an automatic or reflex character; for when once initiated by a voluntary effort they continue for an indefinite period—so long, in fact, as the impressions which the food makes upon the afferent nerves are received by the nerve-centers which regulate and control them. That the masticatory movements are of this reflex nature is shown by the fact that they will be maintained even though the voluntary effort which called them forth has subsided and the attention has been directed to some entirely different subject. It would appear that all that is necessary under such conditions is the exciting action of the food upon the periphery of the afferent nerves distributed to the tongue and mouth.

---

* By this term is meant a combination of nerves, afferent and efferent, and nerve centers which when stimulated coördinates the actions of the organs with which it is associated.

The nerves involved in this reflex are shown in the following table:

Afferent Nerves.	Efferent Nerves,
1. Lingual branch of fifth nerve.	1. Inferior maxillary division of fifth nerve.
2. Glossopharyngeal.	2. Hypoglossal or sublingual.
	3. Facial or portio dura.

The nerve-center coördinating the movements of mastication is situated in the medulla oblongata. The afferent or excitor nerves which receive the impressions of the food are distributed largely to the mucous membrane of the tongue. When these impressions are received by the center in the medulla oblongata, it discharges nerve impulses, which, passing outward through motor nerves, excite contraction in the masticatory muscles. The motor nerves innervating the muscles are: (1) The small root of the fifth nerve, which, after emerging from the cavity of the cranium through the foramen ovale, joins the inferior maxillary division of the large sensor root. It then is distributed to the masseter, temporal, internal, and external pterygoids, anterior belly of the digastric, and mylohyoid muscles, and controls their movements. (2) The hypoglossal nerve, which, after emerging through the anterior condyloid foramen, passes downward and forward to be distributed to the extrinsic and intrinsic muscles of the tongue. (3) The facial or portio dura, which, after emerging from the stylomastoid foramen, is distributed to the muscles of the face. Irritation of any one of these nerves produces convulsive movements in the muscles to which it is distributed, while their division is followed by paralysis of these muscles. The medulla not only generates the impulses which are directly responsible for the movements of mastication, but also coördinates them in such a manner that the movements of mastication may be directed toward the accomplishment of a definite purpose.

INSALIVATION.

Insalivation is the incorporation of the saliva with the food, and takes place for the most part during mastication. The saliva ordinarily present in the mouth is a complex fluid composed of the various secretions of the parotid, submaxillary, and sublingual glands and the muciparous follicles of the mouth, which collectively constitute the salivary apparatus (Fig. 65).

The **parotid gland** is situated in front of and partly below the external ear, where it is held in position by the fascia and skin. From the anterior border of the gland there emerges a duct (Stensen's), which, after crossing the masseter muscle to its anterior border, turns inward, pierces the buccinator, and opens on the surface of the cheek opposite the second upper molar tooth.

The **submaxillary gland** is situated below the jaw in the anterior part of the submaxillary triangle. From the gland there emerges a duct (Wharton's) which opens into the mouth by a minute orifice on the surface of a papilla by the side of the tongue.

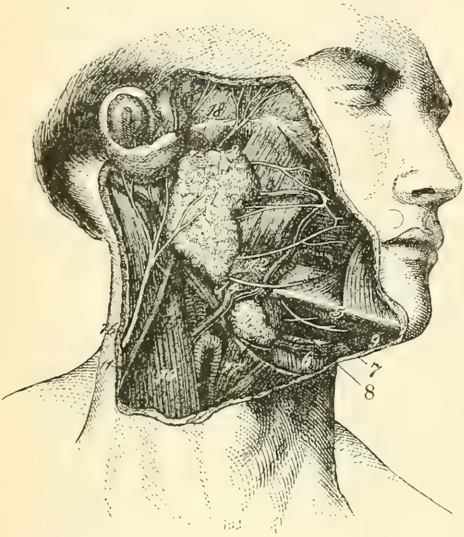

FIG. 65.—SALIVARY GLANDS. 1, 2. Parotid. 3. Duct of Steno. 4. Submaxillary. 5. Sublingual. 6. Mylohyoid muscle. 7. Lingual branch of the fifth nerve. 8. Duct of Wharton. 9. Digastric muscle. 10. Sternomastoid muscle. 11. External jugular vein. 12. Facial vein. 13. Temporal vein. 14, 15. Internal jugular vein. 16. Branch of the cervical plexus. 17. Sublingual nerve.—(*Le Bon.*)

The **sublingual gland** is situated just beneath the mucous membrane in the anterior part of the mouth, where it forms a projection between the gums and tongue. The posterior part of the gland gives origin to a duct (the duct of Rivinus, described also by Bartholin) which opens into the mouth with or very near to the duct of Wharton. The anterior part of the gland gives origin to a varying number of ducts (Walthers) which open separately along the edge of the sublingual plica of the mucous membrane.

Histologic Structure of the Salivary Glands.—In their ultimate structure the salivary glands bear a close resemblance to one another. They are compound tubulo-alveolar glands composed of small irregularly shaped lobules united by areolar tissue and connected by branches of the salivary ducts. Each lobule is made up of a number of small alveoli or acini more or less tubular in shape which are the terminal expansions of the smallest ducts. (See Fig. 66.) The wall of the acinus is formed by a reticulated basement membrane, surrounded externally by blood-vessels, the spaces between which constitute lymph-spaces or channels. The inner surface of the acinus membrane supports a single layer of irregular spheric or polygonic epithelial cells. The cells do not entirely fill up the cavity of the acinus, but leave an intercellular space, the lumen, which constitutes the beginning of the duct for the transmission of the secretion to the mouth. From each acinus there passes a narrow intercalary duct lined by a layer of flattened cells. The common excretory duct—formed by the union of the intralobular and interlobular ducts—consists also of a basement membrane, lined, however, by tall columnar epithelial cells. The salivary glands are abundantly supplied with blood-vessels and nerves which are closely related to their activity.

Based partly on the character of their secretions and partly on the microscopic appearance of their secreting cells, the salivary glands have been divided by Heidenhain into two classes: viz., serous or albuminous, and mucous glands. To the first class belong the parotid, a portion of the submaxillary, and a portion of the glands of the tongue. To the second class belong a portion of the submaxillary gland, the sublingual, a portion of the glands of the tongue, the glands of the cheeks, lips, palate, and pharynx. It is possible that a single alveolus of any gland may contain both albuminous and mucous cells.

In the *serous* glands the cells are more or less spheric in shape, nucleated, and almost completely filled with dark granular material (Fig. 67). In the *mucous* glands the cells are large, clear in appearance, and loaded with a highly refracting material resembling mucin (Fig. 68). Between the basement membrane and the clear cells are to be found in the acini of the submaxillary glands small crescentic shaped cells filled with granular material which stains deeply with various coloring-matters. These are known as the demilunes of Heidenhain. At one time it was supposed that they were young cells destined to take the place of the clear cells which were believed to be exhausted and to have undergone disintegration. At the present time they are regarded as albuminous or serous cells which exhibit changes similar to the cells of the parotid gland.

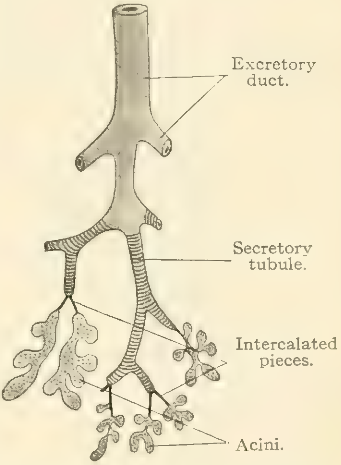

Fig. 66.—Scheme of the Human Submaxillary Gland.—(*Stöhr.*)

The glands embedded in the mucous membrane covering the tongue, lips, cheek, palate, and pharynx are for the most part lined with epithelial cells which contain a highly refracting matter similar to, if not identical with, that found in the cells of the submaxillary and sublingual glands.

Nerve-supply.—Histologic investigation has demonstrated that the cells and blood-vessels of the salivary glands are supplied with nerve-fibers directly from ganglion cells situated in their immediate neighborhood. Thus the cells and blood-vessels of the submaxillary and sublingual glands receive nerve-fibers from the submaxillary, sublingual and superior cervical ganglia, while the cells and blood-vessels of the parotid gland receive nerve-fibers from the otic and the superior cervical ganglia. From their ultimate distribution it may be inferred that some of the ganglion cells and fibers influence the production of the secretions (secretor nerves), while others influence the caliber of the blood-vessels causing either constriction or dilatation (vaso-constrictor and vaso-dilatator nerves). (Fig. 69.) The secretor fibers penetrate the basement membrane enclosing the gland acinus and finally terminate between and on the surface of the secretory cells. The vaso-motor fibers terminate between and on the muscle cells in the walls of the blood-vessels.

The local ganglion cells, however, are in anatomic relation with nerve-trunks coming directly from the medulla oblongata and the spinal cord. As they approach the ganglia, their terminal branches arborize around and closely invest the cells of the ganglia and come into intimate histologic and physiologic connection with them. The nerve-fibers coming from the central nerve system are known as pre-ganglionic fibers, while those coming from the ganglia are known as post-ganglionic fibers. Through the intermediation, therefore, of the ganglion cells, the secretor cells of the salivary glands and the blood-vessels surrounding them, are brought into relation with the central organs of the nerve system and become susceptible of being influenced by them.

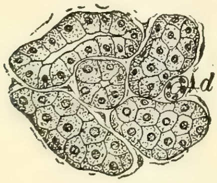

Fig. 67.—Section of Human Parotid Gland Including Several Acini. *d*. Cut intralobular duct.—(*Piersol.*)

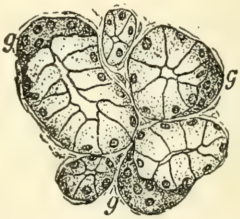

Fig. 68.—Section of Human Sublingual Gland. Among the clear cells lining the mucous acini are nests (*g*, *g*) of granular elements which constitute the demilunes of Heidenhain.—(*Piersol.*)

The Parotid Saliva.—The parotid saliva, as it flows from the orifice of Stensen's duct, is clear, limpid, free from viscidity, distinctly alkaline in reaction, with a specific gravity of 1.003. Chemic analysis shows that it consists of water, a small quantity of proteid matter, a trace of a sulphocyanogen compound, and inorganic salts. The secretion is increased during mastication, and especially on the side engaged in mastication. Dry food causes a larger flow than moist food. The situation of the orifice of the parotid duct is such that as the secretion is poured into the mouth it is at once incorporated with the food by the movements of the lower jaw, and thus fulfils the physical function of softening and moistening it.

The Submaxillary Saliva.—The submaxillary saliva is clear, slightly viscid, alkaline in reaction, and has a specific gravity of 1.002. It consists of water, proteid matter (mucin), and inorganic salts.

The Sublingual Saliva.—The sublingual saliva is clear, extremely viscid, and strongly alkaline in reaction. It consists of water, proteid matter (chiefly mucin), and inorganic salts.

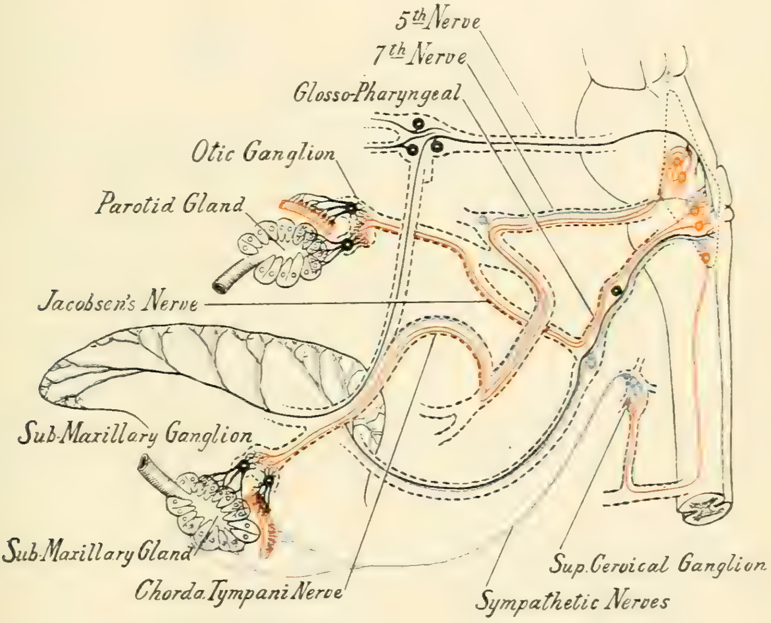
5th Nerve
7th Nerve
Glosso-Pharyngeal
Otic Ganglion
Parotid Gland
Jacobsen's Nerve
Sub-Maxillary Ganglion
Sub-Maxillary Gland
Chorda Tympani Nerve
Sup. Cervical Ganglion
Sympathetic Nerves

FIG. 69.—SCHEME OF THE NERVES INVOLVED IN THE SECRETION OF SALIVA.

The small racemose glands embedded in the mucous membrane on the inner surface of the cheeks and lips, on the hard and soft palate, on the tongue and pharynx, secrete a fluid which is grayish in color, extremely viscid and ropy. It contains a large amount of mucin.

Mixed Saliva.—The saliva of the mouth is a complex fluid composed of the secretions of all the salivary glands. As obtained from the mouth it is frothy, opalescent, slightly turbid, and somewhat viscid. The specific gravity is low, ranging from 1.003 to 1.006. The reaction is usually distinctly alkaline. It may, however, be neutral or even acid in reaction if there is any fermentation of food particles in the mouth or certain disorders of the alimentary canal. When examined with the microscope, the saliva is seen to contain epithelial cells, salivary corpuscles resembling leukocytes, particles of food, various microörganisms, and especially *Leptothrix buccalis*.

The chemic composition of the saliva is shown in the following table:

COMPOSITION OF HUMAN SALIVA.

Water,	995.16	994.20
Epithelium,	1.62	2.20
Soluble organic matter,	1.34	1.40
Potassium sulphocyanid,	0.06	0.04
Inorganic salts,	1.82	2.20
	1000.00	1000.04
	(Jacubowitsch.)	(Hammerbacher.)

Water constitutes the main ingredient, amounting to 99.5 per cent. The soluble organic matter is proteid in character and is a mixture of mucin, globulin, and serum-albumin. The potassium sulphocyanid is mainly derived from the parotid gland. Its presence can be demonstrated by the addition of a few minims of a dilute solution of slightly acidulated ferric chlorid, when a characteristic red color is developed. The inorganic constituents comprise the sodium, calcium and magnesium phosphates, sodium carbonate, sodium and potassium chlorids.

The relative amounts of the different constituents of the saliva will depend on the relative degree of activity of the different glands, and this in turn will be determined by the character of the food. When the food is dry, there will be an excess of the parotid secretion; when it partakes of the consistence of meat, there will be a larger secretion of the submaxillary saliva. The glands apparently adapt their activity to the character of the food.

Quantity of Saliva.—The estimation of the total quantity of mixed saliva secreted in twenty-four hours is exceedingly difficult, and the results obtained must be only approximative. It is, of course, subject to considerable variation, depending upon habit, the nature of the food, etc. The experiments of Professor Dalton and the results obtained by him are eminently trustworthy, and in all probability represent as nearly as possible the exact amount secreted. He found that without any artificial stimulus he was enabled to collect from the mouth about 36 grams (540 grains) of saliva per hour, but that upon the introduction of any stimulating substance into the mouth the quantity could be greatly increased. During mastication the saliva was poured out in greater abundance, the amount depending upon the relative dryness of the food. He found that wheaten bread absorbed 55 per cent. of its weight, and fresh cooked meat 48 per cent. If, therefore, the average quantity of bread and meat required daily by a man of ordinary physical development and activity be assumed to be 540 grams (19 oz.) of the former and 450 grams (16 oz.) of the latter, these two substances would absorb respectively 297 grams (4573.8 grains) and 216 grams (3326.4 grains), making a total of 513 grams (7900 grains). If, therefore, the amount secreted and mixed with the food during an estimated two hours of mastication be added to the amount secreted during the remaining twenty-two hours, supposing that it continues at the rate of 36 grams per hour, we have a total amount of 513 ÷ 792 grams, or 1305 grams (19,780 grains), or about 2.8 pounds.

Histologic Changes in the Salivary Glands during Secretion.—During and after secretion very remarkable changes take place in the cells lining the acini, which are in some way connected with the production of the essential constituents of the salivary fluids. In the case of the parotid gland, which may be regarded as the type of a serous or albuminous gland, the following changes have been observed by Langley (Fig. 70). During the period of rest and just previous to secretory activity, the epithelial cells are enlarged and swollen, and encroach on the lumen of the acinus. The protoplasm of the cells is so completely filled with dark fine granules as not only to obscure the nucleus, but to almost obliterate the line of union of the cells. As soon as secretion becomes active, however, the granules begin to disappear from the outer region of the cell and move toward the inner border and into the lumen of the acinus. From these observations it might be inferred that during rest the protoplasm of the cells gives rise to granular material, and that during and after secretory activity there is an absorption of new material from the lymph and a reconstruction of the granular material.

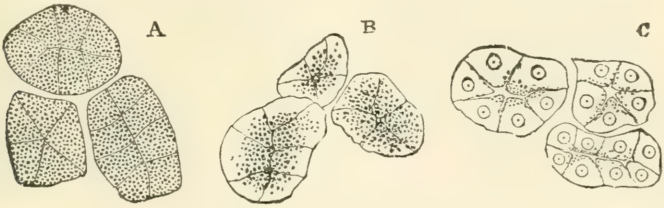

FIG. 70.—CELLS OF THE ALVEOLI OF A SEROUS OR WATERY SALIVARY GLAND. A After rest. B. After a short period of activity. C. After a prolonged period of activity. —(*Yeo's "Text-Book of Physiology."*)

In the submaxillary gland, a portion of which may be taken as a type of a mucous gland, similar changes have been observed (Fig. 71). During rest the epithelial cells are large, clear in appearance, highly refractive, and loaded with small globules resembling mucin. The nucleus, surrounded by a small quantity of protoplasm, lies near the margin of the cell. That the granules are not protoplasmic in character is shown by the fact that they do not stain on the addition of carmine. When treated with water or dilute acids, the globules swell up, coalesce, and form a uniform mass. The chemic relations of this substance indicate that it is the precursor of mucin—namely, mucigen. During secretory activity the cells discharge these mucigen granules into the lumen of the acinus where they are transformed into mucin. Though the appearance of the gland-cell appears to indicate it, there is no evidence for the view that the cell itself undergoes disintegration in the process.

The Physiologic Actions of Saliva.—The constant presence of salivary glands in the different classes of animals and the large amount of secretion they pour daily into the alimentary canal point to the conclusion that this mixed fluid plays an important rôle in the general digestive process. Experiment has demonstrated that it has a two-fold action, physical and chemical.

Physically, saliva softens and moistens the food, unites its particles into a consistent mass by means of its contained mucin, and thus facilitates swallowing.

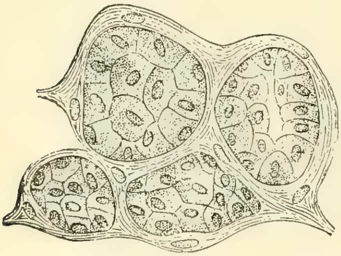

FIG. 71.—THE APPEARANCE PRESENTED BY THE CELLS OF THE SUBMAXILLARY GLAND OF THE DOG AFTER PROLONGED SECRETION. —(*Modified from Landois and Stirling.*)

Chemically it converts starch into sugar. This action is more marked with boiled than with raw starch, a fact which depends on the physical structure of the starch grain. In the natural condition each starch grain consists of a cellulose envelope or stroma in the meshes of which is contained the true starch material, the granulose. When boiled for some minutes, the starch grain absorbs water, the granulose swells and ruptures the cellulose envelope, after which it passes into an imperfect opalescent solution more or less viscid, depending on the relative amounts of water and starch. This is the change largely brought about by the process of cooking. If a portion of this hydrated starch be kept in the mouth for a few minutes it will be converted into sugar, a fact made evident by the sense of taste.

The chemic action of saliva in converting starch into sugar, as well as the intermediate stages, can be experimentally shown in the following manner: To 5 volumes of a thin starch solution in a test-tube add two volumes of filtered saliva. Place the mixture in a water-bath at a temperature of 35° C. In a few minutes the starch passes into a soluble condition and the fluid becomes clear and transparent. On testing the solution from time to time with iodin the characteristic blue reaction will be found to gradually disappear, the color passing from blue to violet, to red, to yellow. If now the solution be boiled with a solution of cupric hydroxid (Fehling's solution) a copious red or yellow precipitate of cuprous oxid is formed, which indicates the presence of sugar. The polariscope shows that this sugar is maltose, $C_{12}H_{22}O_{11}$. During the conversion of the starch intermediate substances are formed to which the term dextrin is applied. After the starch has been rendered soluble it undergoes a cleavage into maltose and a dextrin, which, as it gives rise to a red color with iodin, is termed erythrodextrin. At a later stage this erythrodextrin also undergoes a cleavage into maltose and a second variety of dextrin, which, as it does not give rise to any color with iodin, is termed achroödextrin. It is claimed by some investigators that this form can also in time be transformed into sugar. It is possible that a small quantity of dextrose is also formed.

The successive stages of the conversion of starch into sugar may be represented by the following schema:

$$\text{Starch} = \text{Soluble Starch} = \begin{cases} \text{Erythrodextrin} = \begin{cases} \text{Achroödextrin.} \\ \text{Maltose.} \end{cases} \\ \text{Maltose.} \end{cases}$$

This change consists in the assumption by the starch of a molecule of water, and for this reason the process is termed hydrolysis. The nature of the chemic change is shown in the following formula:

$$\underset{\text{Starch}}{3(C_6H_{10}O_5)} \underset{+}{+} \underset{\text{Water}}{H_2O} \underset{=}{=} \underset{\text{Maltose}}{C_{12}H_{22}O_{11}} \underset{+}{+} \underset{\text{Dextrin.}}{C_6H_{10}O_5}$$

The amylolytic or starch-changing action of saliva depends on the presence of an unorganized ferment or enzyme known as *ptyalin*. This enzyme is present in the secretion of each of the salivary glands. The chemic character of ptyalin is unknown, though there are reasons for believing that it partakes of the nature of a proteid. It is a product in all probability of the katabolic activity of the secretory cells. According to Latimer and Warren, ptyalin is a derivative of the zymogen, ptyalogen. This latter compound has been shown to be present in the glands of the dog, cat, and sheep. Ptyalin effects the transformation of starch merely by its presence, and undergoes no perceptible consumption in the process. The activity of this enzyme is very great, and unless interfered with by an excess of sugar and dextrin, it acts practically indefinitely.

The activity of ptyalin is modified by various external conditions, among which may be mentioned the chemic reaction of the medium in which it is placed. It is most active when the medium is moderately alkaline. Its activity is arrested either by strong alkalies or acids, though the presence of a small percentage of an acid does not appear to have any effect in either hastening or retarding the process. This fact has a bearing upon the question as to whether the action of the saliva is interfered with in the stomach by the presence of the gastric juice. At present it is a disputed matter, but the weight of authority is in favor of the view that the transforming action may continue for almost half an hour during the early stages of gastric digestion. The temperature also influences the rapidity with which the transformation of the starch is effected. At a temperature of 95° to 106° F. the ptyalin acts most energetically, while its activity is entirely arrested by reducing the temperature to the freezing-point or raising it to the boiling-point.

The Nerve Mechanism of the Secretion of Saliva.—The secretion of the saliva is a complex act and involves the coöperation of gland-cells, blood-vessels, and nerves. During the intervals of mastication the glands are practically at rest as far as the *discharge* of saliva is concerned. The cells, however, are actively engaged in absorbing from the surrounding lymph-spaces materials derived from the blood from which they construct their characteristic contents. The blood-vessels possess that degree of dilatation necessary for nutritive purposes.

With the beginning of mastication the blood-vessels suddenly dilate, the blood-supply is increased, and the gland-cells begin to discharge water, inorganic salts, and their organic constituents into the lumen of the acinus. This continues until mastication ceases, when all the structures return to their former condition of relative inactivity. The entire process is reflex in character and takes place through the medulla oblongata. It requires the usual mechanism necessary for all reflex acts—viz., a sentient surface, afferent nerves, emissive cells, efferent nerves, and the responsive organs.

With the introduction of food into the mouth impressions are made on the terminal branches of the afferent nerves distributed in the mucous membrane. Nerve impulses developed by the mechanic and chemic action of the food are then transmitted to the medulla oblongata and received by emissive cells. These in turn discharge nerve impulses which are transmitted through efferent nerves to the structures, producing the vascular and secretory effects already stated.

The nerves and nerve-centers which constitute the reflex mechanism for the secretion of saliva are shown in the following table:

Afferent Nerves.	Nerve-centers.	Efferent Nerves.
1. Lingual branch of fifth nerve.	Medulla oblongata.	Chorda tympani for the submaxillary and sublingual glands, auriculo-temporal branch of the fifth nerve for the parotid gland.
2. Taste fibers in the chorda tympani.		
3. Glossopharyngeal.		Sympathetic nerve for all glands.

That the secretion of the saliva is regulated by the above mechanism, and that the lingual branches of the fifth nerves and the glossopharyngeals are the *afferent nerves*, can be demonstrated by exposing the glands and their nerve connections and subjecting them to experiment. Under such circumstances, if a cannula be placed in the duct of the submaxillary gland, and the lingual nerve stimulated by an induced electric current of moderate strength, a copious flow of saliva at once takes place. If now the glossopharyngeal nerve be stimulated in a similar manner, the effect on the secretion will be the same. Division of these two nerves in an animal, in such a way as to prevent the nerve impulses from reaching the medulla oblongata, is followed by a marked diminution in the amount of saliva secreted. The reflex centers, however, may receive impulses and be excited to activity by impulses coming through other nerves—*e. g.*, the pneumogastric, when the mucous membrane of the stomach is stimulated; the sciatic, when after division its central end is stimulated.

The central mechanism which causes through its efferent nerves the discharge of saliva is also capable of being excited to activity by psychic influences. It is well known that ideas and emotional states developed by the sight and the odor of foods, especially after long abstinence, cause a discharge of saliva into the mouth. The watering of the mouth under such circumstances is a demonstration of the influence of such psychic states. This fact was experimentally demonstrated on dogs by Pawlow. This investigator caused the ducts of the glands to be brought to the surface in such a manner that they healed into the edges of the skin wounds. By means of suitable receivers applied over the orifices of the ducts, the saliva could be readily collected. When the dog, under such circumstances, was tempted by the sight of food there was at once a free discharge of saliva.

Whenever the central mechanism is stimulated, either by nerve impulses coming through afferent nerves, from the periphery or from the brain, impulses are generated which pass outward through *efferent nerves*—the chorda tympani nerve to the submaxillary and sublingual glands, the auriculo-temporal nerve to the parotid gland, and the sympathetic nerve to all three.

The Chorda Tympani.—The chorda tympani nerve is a branch of the facial, the trunk of which it leaves in the aqueduct of Fallopius. It then crosses the tympanic cavity, emerges through the Glaserian fissure, and joins the lingual branch of the inferior maxillary division of the fifth nerve. After passing forward as far as the sublingual gland, nearly all of the original fibers leave the lingual nerve by four or five strands to become connected by terminal branches with nerve-ganglion cells in relation with the submaxillary and sublingual glands. (See Fig. 69.)

The effects on the secretion and flow of saliva from the submaxillary gland which follow division and stimulation of the chorda tympani nerve are shown in the following way: a cannula is inserted into Wharton's duct and the rate of flow estimated; the nerve is then divided, after which the flow ceases. The peripheral end of the nerve is then stimulated with the induced electric current, when a copious secretion of a thin saliva takes place, accompanied by a marked dilatation of the blood-vessels of the gland. The quantity of blood passing through the vessels is so great as to give to the venous blood an arterial hue and to the small veins a distinct pulsation. It would appear from these effects that the chorda contains two sets of fibers, one of which inhibits the action of a local vaso-motor mechanism permitting the blood-vessels to dilate (vaso-dilatator fibers), the other of which stimulates the secretor cells to activity, either directly or through the intermediation of local ganglia. That local ganglia are involved is shown by the effects which follow the injection of nicotin into the circulation. After a sufficient dose—10 milligrams for the cat—stimulation of the chorda has no effect. Stimulation of the nerve-plexus beyond the ganglion, however, is at once followed by vascular dilatation and secretion.

It might be inferred that the increase in the flow of saliva is due to filtration, the result of the increased blood-supply to the gland, and not to the influence of any true secretor fibers stimulating the activities of the secretor cells. That this is not the case, however, can be demonstrated in several ways: First, the pressure in the duct of the submaxillary gland, as shown by the mercurial manometer, rises, when the gland is secreting, considerably above the pressure in the carotid artery, which could not be the case if it were due to a mere filtration; for if pressure alone were the cause, the flow of saliva would cease as soon as the pressure in the tube equaled the pressure in the blood-vessels. Second, even in the absence of blood the gland can be made to yield a secretion, as shown by stimulating the nerve in a recently killed animal. Third, after the injection of atropin into the circulation the secretion is abolished, but the local vaso-motor mechanism is unimpaired, for stimulation of the nerve, as in the previous instance, gives rise to a dilatation of the vessels and an increased blood-supply. There is thus abundant proof that the chorda tympani contains two sets of fibers—one regulating the blood-supply to the gland, the other stimulating the secretor cells.

The Auriculo-temporal Nerve.—The nerve-fibers which conduct nerve impulses outward from the medulla to the parotid gland are believed to pass through the glossopharyngeal nerve, through the tympanic branch or nerve of Jacobson, to the otic ganglion, with which they become connected. From this ganglion new nerve-fibers arise which pass into the fifth nerve and reach the secretor cells of the parotid gland through the auriculo-temporal nerve.

The influence of the auriculo-temporal branch of the fifth nerve on the parotid gland is similar to the action of the chorda tympani on the submaxillary gland. The active fibers of this nerve are probably derived from the ninth nerve or glossopharyngeal. If the nerve be stimulated by the induced electric current, there follows a dilatation of the blood-vessels and an abundant discharge of a thin saliva, rich in water and salts, but containing a small amount of organic matter. Division of the nerve, extirpation of the otic ganglion, or division of Jacobson's nerve, is followed by a loss of reflex secretion. Stimulation of Jacobson's nerve, as shown by Heidenhain, gives rise to the secretion.

The Sympathetic Nerves.—The sympathetic fibers which influence the salivary secretion emerge from the spinal cord mainly through the second, third, and fourth thoracic nerves. After passing into the sympathetic chain they ascend to the superior cervical ganglion, with the cells of which they become connected through the intermediation of fine terminal branches. From this point non-medullated nerve-fibers follow the branches of the external carotid artery to the different glands. There is no evidence that these fibers have any connection, anatomic or physiologic, with local ganglia at or near the submaxillary, sublingual or parotid glands. If the sympathetic nerve in the neck, especially in the dog, be divided and the peripheral end stimulated with the induced electric current, there is at once a contraction of the smaller blood-vessels of the submaxillary and sublingual glands and a diminution of the blood-supply, a result showing the presence of vaso-constrictor fibers. Nevertheless both the submaxillary and sublingual glands pour out a saliva which is different from that poured out when the chorda tympani is stimulated. The quantity is less, it is more viscid, richer in organic matter, of a higher specific gravity, and more active in the transformation of starch into sugar.

Stimulation of the sympathetic fibers passing to the parotid gland is followed by contraction of the vessels and an abolition of the secretion; but at the same time there is an increased activity of the secretor cells, for subsequent stimulation of the auriculo-temporal nerve not only causes an increase in the amount of water and inorganic salts, but an increase also in the amount of organic matter far beyond that produced when the auriculo-temporal has alone been stimulated. Histologic examination shows that the small ducts of the gland are filled with thick organic matter after stimulation of the cervical sympathetic.

The foregoing facts led Heidenhain to the conclusion that there are two physiologically distinct efferent nerve-fibers distributed to the glands, viz., *trophic* nerves, derived from the sympathetic which stimulate the cells to the production of organic constituents; and *secretor* nerves, derived from the cranial nerves, which stimulate the cells to the production of water and inorganic salts. This view has however, been controverted by Langley who regards the secretor fibers to the glands as essentially the same, and considers the differences in the character of the secretion to be dependent on differences in the quantity of the blood-supply induced by the simultaneous stimulation of the vaso-motor nerves.

DEGLUTITION.

Deglutition is that part of the digestive process which is concerned in the transference of the food from the mouth through the pharynx and esophagus into the stomach. This is an extremely complex act and involves the action of a large number of structures, all of which are made to act in proper sequence under the coördinating influence of the nervous system. The deglutitory canal consists of the mouth, pharynx, and esophagus, each of which presents certain anatomic features on which its physiologic action depends.

The cavity of the mouth communicates posteriorly with the pharynx by a narrow orifice, the isthmus of the fauces. This orifice is bounded above by the soft palate, laterally by the anterior and posterior half arches, and below by the tongue.

The pharynx is an oval-shaped cavity extending from the base of the skull to the lower border of the cricoid cartilage, a distance of about 12 centimeters. (See Fig. 72.) Its walls are formed mainly by three pairs of muscles—the superior, middle, and inferior constrictors —each consisting of red, striated muscle-fibers, and hence capable of rapid and energetic contractions. Superiorly the pharynx is attached to and supported by the basilar process of the occipital bone; inferiorly it becomes continuous with the esophagus. The anterior wall of the pharynx is imperfect and presents openings which

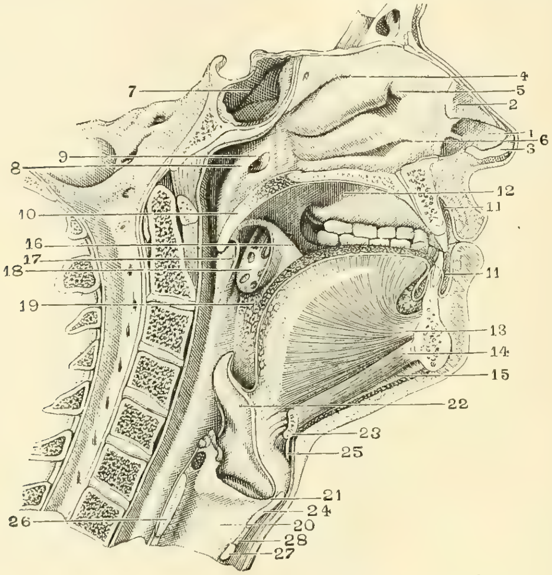

FIG. 72.—VERTICAL SECTION OF THE NASAL FOSSA AND MOUTH. 1. Left nares. 2. Lateral cartilage of the nose. 3. Portion of the internal alar cartilage forming the skeleton of the lower part. 4. Superior meatus. 5. Middle meatus. 6. Inferior meatus. 7. Sphenoidal sinuses. 8. External boundary of the posterior nares. 9. Internal elliptical opening of the Eustachian tube. 10. Soft palate. 11. Vestibule of the mouth. 12. Vault of palate. 13. Genioglossus muscle. 14. Geniohyoid muscle. 15. Cut margin of the mylohyoid muscle. 16. Anterior pillar of the palate (anterior half-arch), presenting a triangular figure with the base inferiorly, covering partly the tonsil. 17. Posterior pillar (posterior half-arch) of the palate. 18. Tonsil. 19. Follicular (mucous) glands at the base of the tongue. 20. Cavity of the larynx. 21. Ventricle of the larynx. 22. Epiglottis. 23. Cut os hyoides. 24. Cut thyroid cartilage. 25. Thyrohyoid membrane. 26. Section of posterior portion of the cricoid cartilage. 27. Section of the anterior portion of the same cartilage. 28. Crico-thyroid membrane.—(*Sappey.*)

communicate with the nasal chambers, the mouth, and the larynx. The lateral wall on either side presents the opening of the Eustachian tube which leads directly into the cavity of the middle ear. The interior of the pharynx is lined by mucous membrane. The pharynx is partially separated from the mouth by the velum pendulum palati, a muscular structure attached above to the hard palate; its lower edge or border is directed downward and backward and presents in the middle line a conical process, the uvula. On either side the palate presents two curved arches, the anterior and posterior, formed respectively by the palato-glossei and palato-pharyngei muscles. The laryngeal orifice or glottis is placed just beneath the base of the tongue. It is triangular in shape, wide in front, narrow behind, and directed downward and backward. It is bounded above by a thin plate of cartilage, *the epiglottis*, placed just behind the tongue and so arranged that it can easily be depressed and elevated.

The esophagus, the continuation of the deglutitory canal, extends downward from the lower border of the cricoid cartilage for a distance of from 22 to 25 centimeters, to a point opposite the ninth thoracic vertebra, where it expands into the stomach. Its walls are composed of an internal or mucous and an external or muscular coat, united by areolar tissue. The muscular coat consists of an external layer of longitudinal fibers arranged in three bands and of an internal layer composed of fibers arranged circularly in the upper part and obliquely in the lower part of the esophagus. In the upper third the fibers are striated; in the middle third they are a mixture of both striated and non-striated; in the lower third they are entirely non-striated.

The muscle fibers surrounding the esophago-gastric orifice are arranged in the form of and play the part of a sphincter muscle, and for this reason may be termed the *sphincter cardiæ* muscle. By its action it prevents a return under normal conditions of food into the esophagus.

The deglutitive act may be for convenience divided into three stages, viz.:

1. The passage of the food from the mouth into the pharynx.
2. The passage of the food through the pharynx into the esophagus.
3. The passage of the food through the esophagus into the stomach.

In the first stage the bolus of food is placed on the superior surface of the tongue. The mouth is then closed and respiration is momentarily suspended. The tip of the tongue is placed against the posterior surfaces of the teeth. The tongue, because of its intrinsic musculature, then arches from before backward against the roof of the mouth and pushes the bolus of food through the isthmus of the fauces into the pharynx. This completes the first stage. It is a voluntary effort and accomplished partly by the tongue, though, as shown by Meltzer, mainly by the mylohyoid muscles.

The second and third stages, or the passage of the food through the pharynx and esophagus into the stomach, have been attributed until quite recently entirely to peristaltic movements of their musculature.* It has been stated that with the passage of the food through the isthmus of the fauces the posterior wall of the pharynx advances and seizes the food, and in consequence of a rapid peristaltic movement running through its constrictor muscles from above downward is transferred to the esophagus; that with the entrance of the food into the esophagus a similar peristalsis, varying in rapidity in different sections in consequence of a change in the character of its musculature, gradually transfers the food into the stomach. There can be but slight doubt that by this method the bolus of food, especially if it is of firm consistence and of a size sufficient to distend the esophagus, is transferred into the stomach, but that it is the exceptional rather than the usual method has been demonstrated by Kronecker, Falk, and Meltzer.

In 1880 the first of these experimenters made the observation that the sensation in the stomach following the swallowing of a mouthful of cold water occurred too quickly to be explained by the prevalent belief that its transference was caused by ordinary peristalsis, the rate of progression of which was known to be slow. Falk then discovered the fact, by introducing through the mouth into the pharynx a tube connected externally with a water manometer, that during the act of swallowing there is a sudden rise of pressure equal to about twenty centimeters of water.

These experiments demonstrated that at the beginning of deglutition there is a sudden rise of pressure, the result of a quickly acting force resident in the mouth or pharynx, in consequence of which the food is rapidly thrown down into the stomach, peristalsis playing no part in the process. The proof, however, of these statements was furnished by Meltzer. This observer introduced into the pharynx and esophagus rubber tubes, the ends of which were provided with thin-walled rubber balloons which could be distended with air. The outer ends of the tubes were connected with Marey's recording tambours. Any compression of the balloon would be followed by the passage of the air into the tambour and an elevation of the lever. With one balloon in the pharynx and the other in the esophagus at varying depths, and the recording levers of the tambours applied against the surface of a revolving cylinder, it became possible, with the addition of a chronogram, to obtain a graphic representation of the time relations of simultaneous and successive compressions of the two balloons.

It was found as the result of many experiments that no matter how deep the position of the esophageal balloon, it was compressed simultaneously with the pharyngeal balloon, as shown by the rise of the levers on swallowing a mouthful of water. The interval of time between the rise of the two levers did not amount to more than the tenth of a second. The inference was that the water was projected or shot down the pharynx and esophagus in this period of time, and in its passage compressed both balloons practically at the same instant. The same was found to be true when small masses of more consistent food were swallowed.

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* Peristalsis may be defined as a progressive wave-like movement which passes over different portions of the walls of the alimentary canal. Its effect physiologically is the propulsion of its solid and semisolid contents. It is characterized by a contraction of the muscle-fibers behind the object and an inhibition or relaxation of the muscle-fibers in front of it. (Bayliss and Starling.)

The curves of the entire deglutitive act recorded by the two levers are, however, different in form. (See Fig. 73.) The pharyngeal curve, 1, presents two crests, the first, A, being due to the compression caused by the passage of the bolus, the second, B, due to the compression exerted by the contraction of the pharyngeal muscles. The interval of time between these two crests amounts to not more than 0.3 second. In the esophageal curve, 3, the elevation, C, corresponds to the elevation, A, and is likewise due to the compression exerted by the bolus. The interval of time between the beginning of the first and second curves was not more than 0.1 second, regardless of the depth to which the esophageal balloon was plunged. At a later period a second rise of the lever was recorded; the time of its appearance, height, duration, etc., were found to increase with the depth of the balloon.

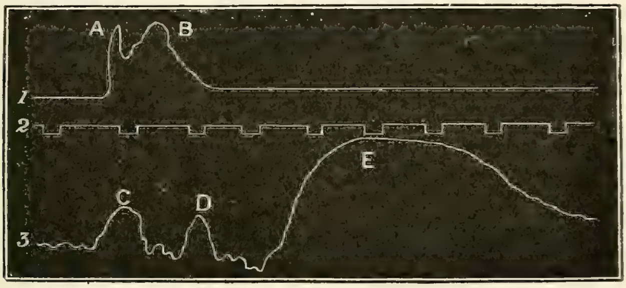


FIG. 73.—TRACING OF THE ACT OF DEGLUTITION. 1. A indicates the compression of the elastic bag caused by the bolus projected by the contraction of the mylohyoid muscles. B. Contraction of the pharynx. 2. Line marking seconds. 3. Tracing of the bag in the esophagus 12 cm. from the teeth. C. Compression of the bag by the bolus corresponding to A. D. Compression by the residues of the bolus carried on by the contraction of the pharynx, B. E. Contraction of the esophagus.—(*Landois and Stirling.*)

These facts demonstrate that deglutition consists of two phases: (1) a rapid rise of pressure in the pharynx, as a result of which the bolus is suddenly shot down to the lower end of the esophagus; (2) a peristaltic contraction of the musculature of the canal, which, acting as a supplementary force, carries onward any particles of food in the canal and forces the bolus through the closed *sphincter cardiæ* at the end of the esophagus.

The immediate cause of the sudden rise of pressure was shown by Meltzer to be the contraction of the mylohyoid muscles. When the nerves going to these muscles were divided in a dog, deglutition was practically abolished. These muscles are probably assisted in their action by the contraction of the hyoglossus muscles as well as the tongue itself.

It was also demonstrated in these experiments that the contraction of the esophagus did not partake of the character of ordinary peristalsis. It was found that the esophagus contracted in three distinct segments, corresponding in all probability to the difference in the character of their muscular fibers. The first segment, about six centimeters in length, was found to begin to contract about 1.2 seconds after the beginning of the first curve and lasting 2 seconds; the second segment, about twelve centimeters in length, beginning to contract about 1.8 seconds or 3 seconds after the beginning of the first section, and lasting for from 5 to 7 seconds; the third segment, six centimeters in length, contracting from 6 to 7 seconds. The beginning and the end of the contraction for each segment occurred simultaneously throughout its entire extent. If, however, a series of deglutitory acts follow each other in quick succession, there is an inhibition of the peristaltic contractions until after the final swallow.

An examination of the action of the esophagus during deglutition, made by Cannon and Moser with x-rays and the fluoroscope, disclosed the fact that the method of food transmission varied in different animals. In the cat and dog the transmission was effected by peristalsis alone. The time required for the food to reach the stomach varied in the cat from nine to twelve seconds and in the dog from four to five seconds. The descent of the bolus was more rapid in the upper than in the lower part of the esophagus. In man, liquids descended rapidly, at the rate of several feet a second, in consequence of the rapid and energetic contraction of the mylohyoid muscles. A peristaltic contraction, passing over the entire esophagus. was necessary to the passage of solid and semisolid food through it,

Closure of the Posterior Nares and Larynx.—Notwithstanding the rise of pressure in the pharynx during the act of swallowing, it is seldom under normal circumstances that any portion of the bolus ever finds its way either into the larynx or nasal chambers, for the reason that the openings of these cavities are fully closed by appropriate means.

At the moment the food passes into the pharynx the posterior nasal openings are closed against the entrance of the food by a septum formed by the pendulous veil of the palate and the posterior half arches. The palate is drawn upward and backward until it meets the posterior wall of the pharynx, and at the same time is made tense, by the action of the levator palati and tensor palati muscles respectively (Fig. 74). This septum is completed by the advance toward the middle line of the posterior half arches caused by the contraction of the muscles which compose them—the palato-pharyngei. When these structures are impaired in their functional activity, as in diphtheritic paralysis and ulcerations, there is not infrequently a regurgitation of food, especially liquids, into the nose.

The larynx is equally protected against the entrance of food during deglutition under normal circumstances. That this accident occasionally happens, giving rise to severe spasmodic coughing, and even in extreme cases to suffocation, is abundantly shown by the records of clinical medicine. Usually it does not occur, for the following reasons: Just preceding and during the act of deglutition there is a complete suspension of the act of inspiration by which particles of food might otherwise be drawn into the larynx; at the same time the larynx is always drawn well up under the base of the tongue and its entrance closed by the downward and backward movement of the epiglottis.

The action here attributed to the epiglottis has been denied by Stuart and McCormick. These observers had the opportunity of looking into a nasopharynx which had been laid open by a surgical operation for the removal of a morbid growth. In this patient, the epiglottis, at the time of deglutition, was always more or less erect and closely applied to the base of the tongue. So complete was this that the food passed over its posterior or inferior surface for a certain distance. In no instance was it ever observed to fold backward like a lid.

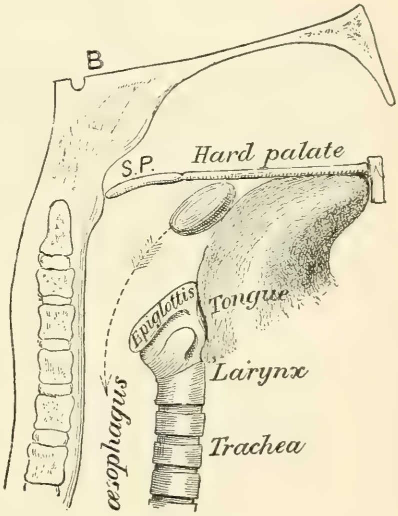


Fig. 74.—Diagram Showing the Manner of Closure of the Posterior Nares and Larynx during Deglutition.—(*Landois and Stirling.*)

Because of the possibility that this position of the epiglottis was due to pathologic causes, Kanthack and Anderson instituted a new series of experiments with a view of determining the action of the epiglottis. As a result of many experiments on animals and of observations on themselves, these observers reaffirm the generally accepted view, that under normal conditions, the entrance of the larynx is always closed by the epiglottis after the manner of a lid.

In addition to the downward and backward movement of the epiglottis and the ascent of the larynx under the base of the tongue, it is also certain from the observations of Meltzer that the larynx is protected from the entrance of food, in the rabbit at least, by the closure of the glottis itself. This experimenter noticed, while observing the interior of the larynx, both from above, through an opening in the hyothyreoid membrane, and from below, through an opening in the trachea that when an act of deglutition was excited by touching the soft palate with a sound, there was simultaneously with the contraction of the mylohyoid muscles, a firm closure of the glottis. This was accomplished by an approximation of the true vocal bands, a close approximation and a downward and forward movement of the arytenoid cartilages, until they almost touched the anterior wall of the thyreoid cartilage. This movement preceded the ascent of the larynx. When the larynx was separated from all surrounding structures with the exception of the laryngeal nerves, a touch of the palate excited the same phenomena. Under such circumstances the closure of the glottis must have been due to the contraction of its own intrinsic muscles and in consequence of a reflex action through the inferior laryngeal nerves.

The Nerve Mechanism of Deglutition.—Deglutition is almost exclusively a reflex act throughout its entire extent, and requires for its inauguration merely a stimulus to some portion of the mucous membrane of the deglutitory canal. The first stage is primarily voluntary, but from inattention to the process may become secondarily reflex. The origin and course of the afferent nerves, stimulation of which excite reflexly the movements of the pharynx and esophagus, however, are practically unknown. In the rabbit deglutition can be excited by stimulating the anterior central part of the soft palate; in man it has not yet been possible to locate an area stimulation of which will give rise to a reflex deglutitory act. Though electric stimulation of the superior laryngeal nerve will cause reflex deglutitory movements, it is obvious that the terminals of this nerve can not be the source of the natural afferent impulses. Stimulation of the glossopharyngeal nerve causes an inhibition of the movements.

The center from which emanate nerve impulses which excite the various muscles to action has been located experimentally in the medulla oblongata just above the alæ cinereæ. The efferent nerves comprise branches of the facial, hypoglossal, motor filaments of the third division of the fifth nerve, motor filaments of the glossopharyngeal and vagus derived in all probability directly from the medulla oblongata. Inasmuch as the different mechanisms of this reflex, act not only in a coördinate but sequential manner, it would appear as if the deglutition center sent out, in response to the nerve impulses coming from a single peripheral area, a series of nerve impulses successively to succeeding portions of the canal, through the groups of nerve-cells corresponding to the origins of the efferent nerves. That this orderly and progressive peristalsis usually observed is due to a sequence of changes in the central nerve system is shown by the fact, that if the esophagus is divided or a ring of it excised, the extremity in connection with the stomach will exhibit a well-marked peristalsis after a short interval, when an act of deglutition is excited in the customary manner. The efferent nerve fibers, which stimulate the esophageal muscles to action are contained in the trunk of the vagi nerves for after their division the peristalsis is abolished.

In addition to this primary reflex mechanism, the esophagus appears to possess a secondary reflex mechanism consisting of a series of reflex arcs, whose afferent and efferent paths are found in the trunk of the vagus and both connected with successive portions of the esophagus. The first mechanism is temporarily suspended during deep anesthesia while the second persists. (Meltzer.)

Though the peristalsis of the esophagus is excited by nerve impulses coming through the vagus nerves and is abolished by their division, Cannon has shown by means of the Röntgen rays that this effect for the lower portion of the esophagus, at least in the cat and monkey, is of a temporary duration only, lasting from one to several days, after which a peristalsis again develops and of sufficient vigor to force food through the cardiac orifice into the stomach. The muscle coat of this portion of the esophagus is composed of non-striated muscle-fibers, is supplied with a myenteric nerve plexus and resembles lower portions of the alimentary canal. It is capable of developing a peristalsis, solely in response to the pressure of food within and independent of extrinsic nerves.

GASTRIC DIGESTION.

After the food has passed through the esophagus it is received by the stomach, where it is retained for a variable length of time, during which important changes are induced in its physical and chemic composition. The disintegration of the food inaugurated by mastication and insalivation is still further carried on in the stomach by the solvent action of the acid fluid there present, until the entire mass is reduced to a liquid or semiliquid condition.

The **stomach** is dilated and highly specialized portion of the alimentary canal intervening between the esophagus and small intestine. When moderately distended with food, it is somewhat conical or pyriform in shape and slightly curved on itself. It is situated obliquely and in some individuals almost vertically in the upper part of the abdominal cavity, extending from the left hypochondrium to the right of the epigastrium. The dimensions and capacity of the stomach undergo considerable periodic variation according to the extent to which it is distended by food. In the average condition it measures in its long diameter from 25 to 35 centimeters, in its vertical diameter at the cardia 15 centimeters, in its antero-posterior diameter from 11 to 12 centimeters. The capacity of the stomach varies from 1500 to 1700 c.c. In the empty condition its walls are contracted and partly in contact, and the entire organ is drawn up into the upper part of the abdominal cavity. The opening through which the food passes into the stomach is known as the esophago-gastric orifice or the cardia. The opening through which it passes into the intestine is known as the pylorus, the pyloric or gastroduodenal orifice. Between these two orifices the stomach along its upper border presents a curve and along its lower border a much larger curve, known as the lesser and greater curvatures respectively. The left end of the stomach is termed the fundus or cardiac end; the right, the pyloric end. Passing from the fundus toward the pylorus, the stomach gradually narrows, and at a point situated about 5 cm. from the pyloric opening it frequently presents a constriction which divides the general cavity into two portions: viz., the fundus and the antrum of the pylorus.

The walls of the stomach are formed by four distinct coats united by areolar tissue and named, from without inward, as the serous, muscle-, submucous, and mucous.

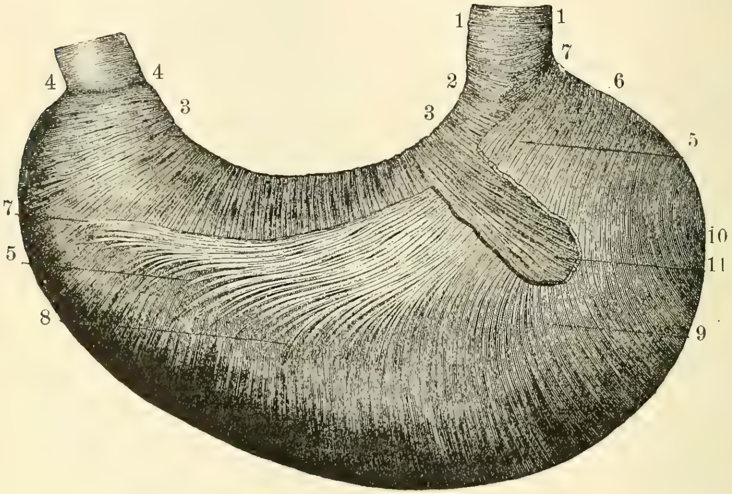


FIG. 75.—FIBERS SEEN WITH THE STOMACH EVERTED. 1, 1. Esophagus. 2. Circular fibers at the esophageal opening. 3, 3. Circular fibers at the lesser curvature. 4, 4. Circular fibers at the pylorus. 5, 5, 6, 7, 8. Oblique fibers. 9, 10. Fibers of this layer covering the greater pouch. 11. Portion of the stomach from which these fibers have been removed to show the subjacent circular fibers.—(*Sappey.*)

The *external* or *serous coat* is thin and transparent and formed by a reduplication of the general peritoneal membrane.

The *middle* or *muscle-coat* consists of three layers of non-striated muscle-fibers, named from their direction the longitudinal, circular, and oblique (Fig. 75). The longitudinal fibers are most abundant along the lesser curvature and are a continuation of those of the esophagus; over the remainder of the stomach they are thinly scattered, but toward the pyloric orifice they are more numerous and form a tolerably thick layer which becomes continuous with the fibers of the small intestine. The circular fibers form a complete layer encircling the entire organ, with the exception, perhaps, of a portion of the fundus. The fibers of this coat cross the longitudinal fibers at right angles. At the lower end of the esophagus and surrounding the cardia the circular muscle fibers form a true sphincter which is known as *sphincter cardiæ*. At the junction of the fundus with the pyloric antrum the circular fibers are arranged in a well-defined bundle termed the *sphincter antri pylorici*. In the pyloric region the circular fibers are more closely arranged, forming thick well-defined rings. At the pyloric opening the circular fibers are again crowded together and form a distinct muscle band—the *sphincter pylori*—which projects for some distance into the interior of the stomach. It has been stated by Rüdinger that the inner fibers of the longitudinal coat become connected with this circular band and constitute a distinct muscle, the *dilatator pylori*. The oblique fibers are most distinct over the cardiac portion of the stomach, but extend from left to right as far as the junction of the middle and last thirds of the stomach. They are continuations of the circular fibers of the esophagus.

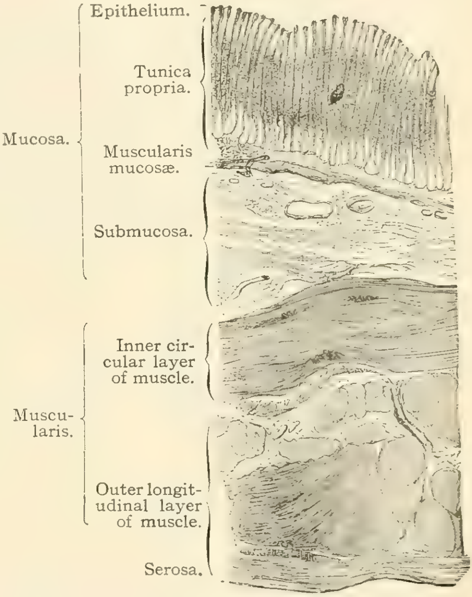


FIG. 76.—TRANSVERSE SECTION OF THE WALL OF A HUMAN STOMACH. × 15. The tunica propria contains glands standing so close together that its tissue is visible only at the base of the glands toward the muscularis mucosæ.—(*Stöhr.*)

The *submucous coat* consists of loose areolar tissue carrying blood-vessels, nerves, and lymphatics. It serves to unite the muscle to the mucous coat. Its inner surface bears a thin layer of muscular tissue, the *muscularis mucosa*, which supports the mucous membranes.

The *internal* or *mucous coat* is loosely attached to the muscular coat. In the empty and contracted state of the stomach it is thrown into longitudinal folds, or rugæ, which are, however, obliterated when the organ is distended with food. The mucous membrane in adult life is smooth and velvety in appearance, gray in color, and covered with a layer of mucus. Its average thickness is about one millimeter. The surface of the membrane is covered with a layer of columnar epithelial cells, each of which possesses a nucleus and nucleolus. At the pylorus there is a circular involution of the mucous membrane which is known as the *pyloric valve.* This is strengthened by fibrous tissue and embraced by the sphincter muscle previously described.

Gastric Glands.—The surface of the mucous membrane when examined with a low magnifying power presents throughout innumerable depressions polygonal in shape and separated by slightly elevated ridges. At the bottom of these spaces are to be seen small orifices, which are the mouths of the glands embedded in the mucous membrane. A vertical section of the gastric walls (Fig. 76) shows not only the position and appearance of the glands, but the relation of the various tissues which enter into the formation of these walls. An examination of the mucous membrane in different regions of the stomach reveals two distinct types of glands, cardiac or fundic, and pyloric, which differ not only in histologic structure, but also in function. Both types extend through the entire thickness of the mucosa.

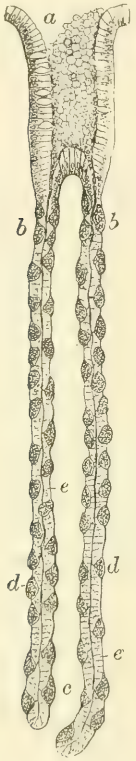


Fig. 77.—Peptic Gland from Stomach of Dog. *a.* Wide mouth and duct which receive the terminal divisions of the gland. *b, c.* Neck and fundus of the tubes. *e.* Central or chief cells. *d.* Parietal or acid cells. —(*After Piersol.*)

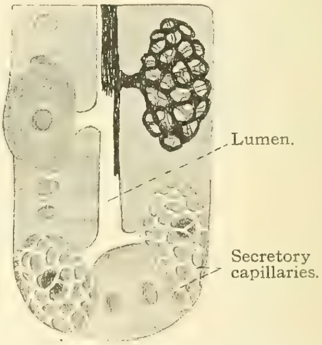


Fig. 78.—Section of Fundus Gland of Mouse. Left upper half drawn after an alcohol preparation, right upper half after a Golgi preparation. The entire lower portion is a diagrammatic combination of both preparations.—(*Stöhr.*)

The *cardiac* or *fundic* glands are formed by an involution of the basement membrane of the mucosa and lined by epithelial cells. Each gland may be said to consist of a short duct, or neck, and a body, or fundus (Fig. 77). The latter portion is wavy or tortuous and frequently subdivided into as many as 8 to 10 distinct and separate tubules. The duct is lined by columnar epithelial cells similar to those covering the surface of the mucosa. The lumen of the fundus is bordered by epithelial cells, cuboid in shape, and consisting of a granular protoplasm containing a distinct spherical nucleus. These cells are generally spoken of as the *chief* or *central* cells. In addition to the chief cells, the fundus contains a second variety of cell, which is of a larger size, of a triangular or oval shape, and consisting of a finely granular protoplasm. From their situation in and just beneath the gland wall they have been termed *parietal* or *border* cells. Each parietal cell appears to be surrounded and penetrated by a system of passages which open into the lumen of the gland by means of a delicate cleft or canaliculus (Fig. 78). Glands with these histologic features are most abundant in the middle zone of the stomach.

The *pyloric glands* are also formed by an involution of the mucous membrane and lined by epithelial cells (Fig. 79). The ducts are much longer than the ducts of the fundic glands. At its extremity each duct becomes branched, giving rise to a number, from 2 to 16, of short tubes, each of which has a large lumen and communicates with the duct by a narrow short neck. The ducts are lined throughout by columnar epithelium. According to Mall, the total number of openings on the surface of the mucous membrane of the dog's stomach is somewhat over 1,000,000, and the total number of blind tubes opposite the muscularis mucosa exceeds 16,500,000. According to Sappey, the surface of the mucous membrane of the human stomach presents over 5,000,000 orifices of gastric glands.

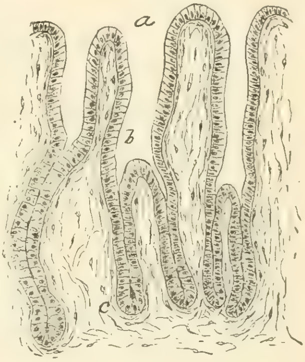


FIG. 79.—SECTION OF PYLORIC GLANDS FROM HUMAN STOMACH. *a*. Mouth of gland leading into long, wide duct (*b*), into which open the terminal divisions. *c*. Connective tissue of the mucosa.—(*After Piersol.*)

Blood-vessels, Nerves, and Lymphatics.—The *blood-vessels* of the stomach after entering the mucosa break up into a number of branches which are distributed to the muscular and mucous coats. The branches to the latter soon form a capillary network with oblong meshes which not only surround the tubules but form a network just beneath the surface of the mucosa. Veins gradually arise from the capillaries which empty into the larger veins of the mucosa. The glands are also supported by processes of smooth muscle-fibers passing up from the muscularis mucosa.

The *nerve-fibers* distributed to the stomach are derived from the vagus and the sympathetic branches of the solar plexus. After piercing the serous coat the fibers form or unite with a plexus of fibers situated between the circular and longitudinal layers of the muscle-coat. At the nodal points of this plexus large nerve-ganglion cells are to be found, the whole forming the mechanism known as Auerbach's plexus. A similar plexus of cells and fibers in more or less intimate anatomic connection with the foregoing is found between the muscle and submucous coats, and is known as Meissner's plexus. From this plexus fine nerve filaments are distributed to muscle-fibers, blood-vessels, and glands. In the latter structure terminal arborizations have been detected in close contact with the secreting cells themselves.

The *lymphatics*, which are quite numerous, originate in the meshes of the mucosa. The larger trunks enter lymph-glands lying along the greater and lesser curvatures of the stomach.

Gastric Fistulæ.—The general process of digestion, as it takes place in the stomach, has been studied in human beings and animals with a fistula in the walls of the stomach and abdomen, the result either of accident or of necessary surgical or experimental procedures.

The earliest observations on gastric digestion were made by Dr. Beaumont on Alexis St. Martin, who, as the result of a gunshot wound, was left with a permanent fistulous opening into the fundus of the stomach. This opening two years after the accident was about two and a half inches in circumference and usually closed from within by a fold of mucous membrane which prevented the escape of the food. This valve could be readily displaced by the finger and the interior of the stomach exposed to view. After the complete recovery of St. Martin, Dr. Beaumont during the years between 1825 and 1831 at intervals made numerous experiments on the nature of gastric digestion. As the result of an admirable series of investigations it was established that the digestion of the food is largely a chemic act, due to the presence of an acid fluid secreted by the mucous membrane; that this fluid is secreted most abundantly after the introduction of food into the stomach; that different articles of food possess varying degrees of digestibility; that the duration of digestion varies according to the nature of the food, exercise, mental states, etc., and that the process is aided by continuous movements of the muscular walls.

Since Dr. Beaumont's time the establishing of a gastric fistula in human beings has been necessitated by pathologic conditions of the esophagus. After recovery these cases offered fair facilities for the study of the process when the food was introduced through the opening. Similar fistulæ have been established in both carnivorous and herbivorous animals with a view of studying the process as it takes place in them. The results obtained in these instances in many respects corroborate those obtained by Dr. Beaumont, though many new facts, unobserved by him, have been brought to light.

Much additional information as to the mode of secretion and the characteristics of the gastric juice has been obtained, since the introduction of two new procedures by Pawlow. The first consists in establishing a gastric fistula and subsequently dividing the esophagus in the neck, and then so adjusting the divided ends that they heal separately into an angle of the skin incision. The second procedure consists in forming a diverticulum or pouch out of the cardiac end of the stomach which opens on the surface of the abdomen but is separated from the rest of the stomach by a thin septum formed of two layers of mucous membrane. (Fig. 80.) The serous and muscle-coats of this pouch are in direct continuity with the large stomach and all possess the same vascular and nerve connections. Because of this fact this miniature stomach, about one-tenth the size of the natural stomach, exhibits the same phenomena, so far as the secretion of the gastric juice is concerned, that the large stomach does. The phenomena which are observed in it may be taken as an indication as to the phenomena which are taking place in the natural stomach.

By the first procedure it is possible to feed an animal with different kinds of food and to observe the effects of psychic states on the secretion of gastric juice. As the swallowed food is discharged from the lower end of the divided esophagus the appetite continues, and hence the animal will eat for several hours. By the second procedure it is possible to collect gastric juice from the miniature stomach and to study the effects on its quantity and quality produced by psychic states, mastication, different articles of food, and by the process of digestion itself as it goes on in the large stomach. In both instances the juice is obtained free from admixture with saliva or food.

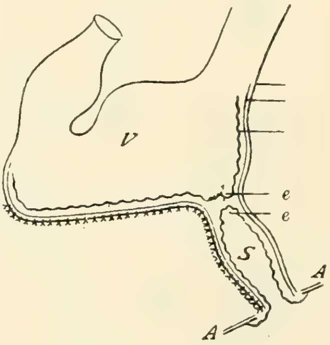


Fig. 80.—Diagram Showing the Relation of the Natural Stomach to the Miniature Stomach or Pouch made According to the Procedure Devised by Pawlow. *V*. The natural stomach. *S*. The minature stomach. *e, e*. The septum formed by the mucous membrane. *A, A*. The abdominal walls.

Gastric Juice.—The gastric juice obtained from the human stomach free from mucus and other impurities is a clear, colorless fluid with a constant acid reaction, a slightly saline and acid taste, and a specific gravity varying from 1.002 to 1.005. The juice obtained from the dog's stomach possesses essentially the same characteristics, though its acidity as well as its specific gravity are slightly greater. When kept from atmospheric influences, it resists putrefactive change for a long period of time, undergoes no apparent change in composition, and loses none of its digestive power. It will also prevent and even arrest putrefactive change in organic matter. The chemic composition of the gastric juice has never been satisfactorily determined, owing to the fact that the secretion as obtained from fistulous openings has not been absolutely normal. The following analyses represent the composition of a sample obtained by Schmidt from the stomach of a woman who had a fistula, but who was nevertheless in good health; also the composition of the juice from a dog:

COMPOSITION OF GASTRIC JUICE.

	Human.	Dog.
Water,	994.40	973.06
Organic matter,	3.19	17.13
Hydrochloric acid,	0.20?	3.34
Calcium chlorid,	0.06	0.26
Sodium chlorid,	1.46	2.50
Potassium chlorid,	0.55	1.12
Calcium phosphate	0.12	1.73
Magnesium "		0.23
Ferric "		0.08
Ammonium chlorid,	....	0.47

The organic matter present in gastric juice is a mixture of mucin and a proteid, products of the metabolic activity of the epithelial cells on the surface of the mucous membrane and of the chief or central cells of the gastric glands respectively. Associated with the proteid material are two ferment or enzyme bodies, termed pepsin and rennin. As is the case with other enzymes, their true chemic nature is practically unknown.

Pepsin, though present in gastric juice, is not present as such in the chief cells of the glands, but is derived from a zymogen, propepsin or pepsinogen, when the latter is treated with hydrochloric acid. This antecedent compound is related to the granules observed in and produced by the cell protoplasm during the period of rest. Though pepsin is largely produced by the central cells of the fundic glands, it is also produced, though in less amount, by the cells of the pyloric glands. Pepsin is the chief proteolytic agent of the gastric juice and exerts its influence most energetically in the presence of hydrochloric acid and at a temperature of about 40° C. Other acids— *e. g.*, phosphoric, nitric, lactic, etc.—are also capable of exciting it to activity, though with less intensity.

Rennin or *pexin* is present in the gastric juice not only of man and all the mammalia, but also of birds and even fish. In its origin from a zymogen substance, in its relation to an acid medium and an optimum temperature, it bears a close resemblance to pepsin. Its specific action is the coagulation of milk, a condition due to the cleavage of caseinogen into a solid flaky body, casein, and a soluble, albumin.

Hydrochloric acid is the agent which gives to the gastric juice its normal acidity. Though the juice frequently contains lactic, acetic, and even phosphoric acids, it is generally believed that they are the result of fermentation changes occurring in the food, the result of bacterial action. The percentage of hydrochloric acid has been the subject of much discussion. The analysis of human gastric juice made by Schmidt shows a percentage of 0.02, while that of the dog is 0.34. It is probable, however, that the low percentage of HCl in human gastric juice was due to the admixture with saliva. At present it is believed from analyses made for clinical purposes that the acid is present to the extent of at least 0.2 per cent. This degree of acidity is not constant during the entire process of digestion. In the earlier as well as in the later stages it is much less.

The immediate origin of the hydrochloric acid is difficult of explanation. That it is derived, however, primarily from the chlorids of the food and secondarily from the blood-plasma has been established by direct experiment. If all the chlorids be removed from the food and all chlorids be withdrawn from the animal tissue by the administration of various diuretics—*e. g.*, potassium nitrate—there will be a total disappearance of hydrochloric acid from the stomach. On the addition of sodium or potassium chlorids to the food, there is at once a reappearance of the acid.

As to the nature of the process by which the acid is formed, nothing definite is known. Various theories of a chemic and physical character have been offered, all of which are more or less unsatisfactory. As no hydrochloric acid is found either in the blood or lymph, the most plausible view as to its origin is that which regards it as one of the products of the metabolism of the gland-cells, and more particularly of the parietal or border cells, and which for this reason have been termed acid-producing or *oxyntic* cells. From the chlorids furnished by the blood the chlorin is derived, which, uniting with hydrogen, forms the HCl. The base set free returns to the blood, which in part accounts for its increased alkalinity during digestion as well as the diminished acidity of the urine. The acid thus formed passes through the canaliculi, which penetrate and surround the cells, into the lumen of the gland.

Hydrochloric acid exerts its influence in a variety of ways. It is the main agent in the derivation of pepsin and rennin or pexin from their antecedent zymogen compounds, pepsinogen and pexinogen (Warren); it imparts activity to these ferments; it prevents and even arrests fermentative and putrefactive changes in the food by destroying microörganisms; it softens connective tissue, it dissolves proteids and acidifies the proteids, thus making possible the subsequent action of pepsin.

The inorganic salts of the gastric juice are probably only incidental and play no part in the digestive process.

Mode of Secretion.—The observations of Dr. Beaumont and the experiments of many physiologists have made it certain that the secretion of the gastric juice is intermittent and not continuous, that it is only on the introduction and digestion of the food that the normal amount is poured out. During the intervals of digestive activity the stomach is practically free from all traces of the juice. The mucous membrane is pale and covered with a layer of mucus having an alkaline or neutral reaction. The introduction, however, of small portions of food or irritation with a glass rod causes a change in the appearance of the mucous membrane. At the points of irritation the membrane becomes red and vascular and in a few minutes small drops of a secretion make their appearance; these coalesce and run down the sides of the stomach.

The statements of Beaumont and many subsequent investigators that the secretion thus obtained is gastric juice have been apparently disproved by Pawlow, who asserts that it is only an alkaline mucous the function of which is protective in character. Mechanic stimulation is incapable of exciting the secretion.

The primary stimulus to gastric secretion, according to Pawlow, is a psychic state induced, on the one hand, by the sight or the odor of food especially if the animal is hungry and the food appetizing; and on the other hand by the mastication of food which is agreeable to the animal. Thus when a dog was tempted by the sight of food, the secretion made its appearance at the end of six minutes and during the time of the experiment, which lasted for an hour and a half, 80 cubic centimeters of the juice were obtained. This is known as psychic or appetite juice. The character of a psychic state, however, greatly influences the amount of the juice secreted. Agreeable emotions increase, depressing emotions inhibit it. Again when a dog with a divided esophagus and a gastric fistula was subjected to sham feeding, mastication continued for five or six hours during which time 700 cubic centimeters of juice were obtained from the stomach. Similar results have been obtained in human beings with an occluded esophagus and a gastric fistula. It is evident from these facts that the secretion of gastric juice is favorably influenced by the sight and odor of appetizing food, by exhilarating emotional states and thorough mastication.

Though the secretion of the gastric juice can be initiated by these means, the amount secreted is but small compared with the quantity secreted after digestion has begun. Then it is that the blood-vessels dilate to their full capacity and furnish for several hours the requisite materials for the production of the juice on a relatively large scale. That some factor is active and keeping up the secretion in the large stomach, is apparent from the increase in the quantity and the change in the quality of the juice secreted by the miniature stomach. This secondary stimulus to the gastric secretion is in all probability chemic in character and developed in the stomach or in its walls during digestive activity, inasmuch as the secretion takes place independent of nerve influences and after division of all afferent and efferent nerves that pass from and to the stomach.

On the assumption that this factor might be developed in the walls of the stomach itself, Edkins conducted a series of experiments, the results of which lead to the inference that there is developed in the pyloric mucous membrane, by the action of the first products of digestive activity a chemic agent which, absorbed by the blood, is carried to the glands throughout the stomach and which stimulates their cells in a specific manner. For this reason it has been called the gastric hormone or the gastric secretin. Whatever the agent or the mechanism may be, there is not only an increase in the quantity but a change in the quality of the juice in accordance with the character of the food; in other words, there is an adaptation of the juice to the kind of food to be digested. Thus the protein of bread causes a secretion of five times more pepsin than the same amount of the protein of milk, while the protein of meat causes secretion of 25 per cent. more pepsin than milk. Meat extract and bouillon have a very stimulating effect on the quantity of juice produced, while alkalies have an inhibitor effect.

Histologic Changes in the Gastric Cells during Secretion.—During the periods of rest and secretor activity the cells of the gastric glands undergo changes in histologic structure which are believed to be connected with the production of the enzymes, pepsin and rennin, and the acid. In the resting period the protoplasm of the chief or central cells of the fundus glands becomes crowded with large and well-defined granules, which during the period of secretory activity largely disappear, so much so, that only the luminal border of the cell is occupied by them, the outer border being clear and hyaline in appearance. The parietal cells during rest are large and finely granular, but after secretion they are smaller in size though still granular. (See Fig. 81, *A* and *B*.)

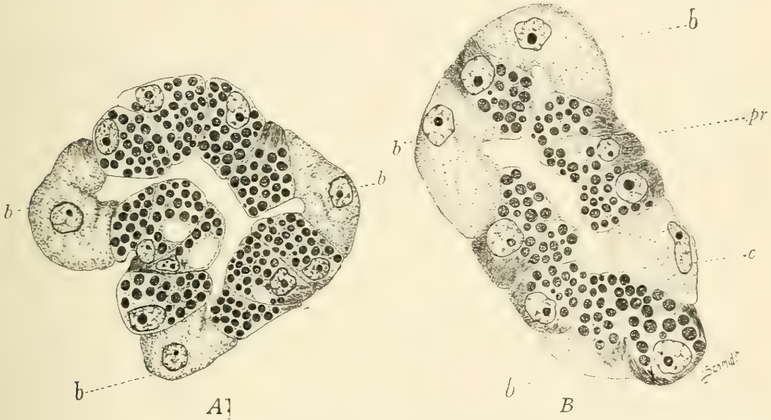


FIG. 81.—SECTIONS OF DEEP ENDS OF FUNDUS GLANDS OF THE CAT IN DIFFERENT SECRETIVE PHASES. × 1000.—(*Bensley.*) *A*. From a fasting stomach. The chief cells are filled with large zymogen granules; nuclei near the outer ends of cells. Gentian-violet preparation. *b b b*. Border cells. *B*. Six hours after an abundant meal of raw flesh. The chief cells exhibit two zones, the inner occupied by large zymogen granules, the outer by a deeply staining, obscurely fibrillar element, *prozymogen;* the nuclei lie at the junction of the two zones. *b b b*. Border cells. *pr*. Prozymogen. *c*. Mucin-secreting cell, similar to those found in the neck of the gland. Gentian-violet preparation.—(*Hemmeter after Bensley.*)

The cells of the pyloric glands, though containing granules, do not show any marked difference between the resting and active condition. According to some observers, they contain pepsinogen; according to others, mucin. The epithelial cells lining the ducts of the pylorus and fundus glands, if not identical with the epithelial cells on the surface of the mucous membrane, pass by transitional forms into them. Among these cells are found many goblet cells which secrete a portion of the mucus found in the stomach and gastric juice. In the period of rest the protoplasm of the epithelial cells absorbs and assimilates from the surrounding lymph-spaces material which eventually makes its reappearance as a product of metabolism in the form of granules and hydrochloric acid. With the onset of digestive activity there is a dilatation of the blood-vessels, an increase in the blood-supply, a stimulation through the nerve-supply of the cells, and an output of a fluid to which the name gastric juice is given.

Influence of the Nerve System.—The primary secretion of gastric juice is a reflex act and under the control and influence of the central nerve system. Experimental investigations render it probable that the central mechanism is located in the medulla oblongata and that the efferent path lies in the trunk of the vagus nerve. Though this nerve has been the subject of much experimentation, the results which have been obtained have not been uniform. The investigations of Pawlow seem to be the most reliable. He found that after division of the nerve, secretion was arrested, and that stimulation of the peripheral ends with induced electric currents at the rate of one or two per second, after a latent period of several minutes' duration caused a flow of gastric juice. This center is excited to activity by nerve impulses descending from the cerebrum as shown by the effects which follow the development of psychic states caused by the sight or the odor of food, as well as by the mastication of agreeable food; for with their development there is a dilatation of blood-vessels and a copious discharge of the juice in a few minutes, showing the coöperation of both vaso-motor and secretor nerves. It is uncertain if the medullary center can be influenced by nerve impulses reflected from the stomach.

The Physiologic Action of Gastric Juice.—In the study of the physiology of gastric digestion as it takes place under normal conditions it is important to bear in mind that the foods introduced into the stomach are heterogeneous compounds consisting of both nutritive and non-nutritive materials, and that before the former can be digested and utilized for nutritive purposes they must be freed from their combinations with the latter. This is accomplished by the solvent action of the gastric juice, which in virtue of the chemic activity of its constituents on proteids, gradually disintegrates the food and reduces it to the liquid or semiliquid condition.

The nature of this change and the respective influence which the acid and pepsin exert can be studied with almost any form of proteid. The most suitable form, however, is coagulated fibrin obtained from blood by whipping and thoroughly freed from blood by washing under a stream of water. The chemic features of proteins, as well as the typical forms contained in the different articles of food, have been considered in connection with the chemic composition of the body and the composition of foods (see pages 16 and 139). For purposes of experimentation artificial gastric juice may be employed. This is as effective as the normal secretion and in no essential respect differs from it. A glycerin extract of the mucous membrane acidulated with 0.2 per cent. hydrochloric acid is probably the best.

If the small pieces of fibrin be suspended in clear gastric juice and kept at a temperature of 104° F. (40° C.) for an hour or two, they will be dissolved and will entirely disappear, giving rise to a slightly opalescent mixture. In the early stages of the process the fibrin becomes swollen and transparent and partly dissolved. If at this time the solution be carefully neutralized, the dissolved portion can be regained in the form of acid-albumin or syntonin—a fact which indicates that the first effect of the gastric juice is the acidification of the proteids. This having been accomplished, the pepsin becomes operative, and in a varying length of time transforms the acid-albumin into a new form of proteid, termed peptone. This form of proteid differs from all other forms of proteid in being soluble in both acids and alkalies and non-coagulable by heat. In the transformation of acid-albumin into peptone it is possible to isolate by the addition of magnesium sulphate and ammonium sulphate intermediate bodies to which the term *albumoses* or *proteoses* has been given, and which differ somewhat in their solubility. The proteoses are termed, from the order in which they make their appearance, primary and secondary. The primary proteoses are precipitated by magnesium sulphate, the secondary by ammonium sulphate. As some of the primary proteoses are soluble in water while others require in addition sodium chlorid for their solution, they have been divided into two groups—viz.: proto- and hetero-albumoses. The secondary proteoses or deutero-albumoses are soluble in water. Though in the subjoined scheme two forms of deutero-albumose are represented and two forms of peptone developed out of them, the results of chemic investigation would indicate that there is but one form of deutero-albumose and hence but one form of peptone. This supposed change produced by gastric juice is represented by the following scheme:

Albumin

Acid-albumin

Proto-albumose = (Primary Proteoses) = Hetero-albumose

Deutero-albumose (Secondary Proteoses) = Deutero-albumose

Peptone (Ampho-peptones) Peptone.

From the fact that when peptones are subjected to the prolonged action of pancreatic juice there arise compounds such as leucin, tyrosin, aspartic acid, arginin, etc., it was believed that two kind of peptones were formed out of a simple protein one of which succumbed to the destructive action of pancreatic juice, while the other resisted it; for this reason the latter was termed *anti-* and the former *hemi-peptone.* The two were included under the term *ampho-peptone.* It is generally admitted now, however, that the body termed anti-peptone is not a peptone at all, but a compound termed *carnic acid* and which is also separable into leucin, tyrosin, etc. Hemi-peptone has never been isolated. The probabilities are, therefore, that but one form of peptone is developed from any given simple protein.

Nearly all forms of protein are in a similar manner transformed into peptones by gastric juice. Beyond this stage, however, there does not seem to be any further change, peptones apparently being the final products of gastric digestion. The intimate nature of this change is practically unknown, but there are reasons for thinking that it is a process of hydration, attended by cleavage, with increasing solubility of the resulting products.

Characters of Peptones.—The peptones resulting from the digestion of different proteins, though resembling each other in many respects, yet possess different chemic characteristics, as shown by their reaction to various chemic reagents. Though having some resemblance to the proteids from which they are derived, they are to be distinguished from them by the following general characteristics:

1. They are not coagulable either by heat or by nitric acid.
2. They are soluble in water, either hot or cold, and in acid and alkaline solutions.
3. They are diffusible, passing through animal membranes with great rapidity. It has been demonstrated that peptones diffuse about twelve times as rapidly as the proteids from which they are derived.

Neither on fat nor starch has gastric juice any appreciable effect, and when these substances are introduced into the stomach they pass into the intestine unchanged. It has been stated, however, that the gastric mucosa produces a fat-splitting enzyme, but that its action is prevented by the presence of the hydrochloric acid. Notwithstanding the fact that dilute solutions of hydrochloric acid (0.3 per cent.) will promptly invert cane-sugar into dextrose and levulose, and that gastric juice will accomplish the same result in test-tubes, there is no strong evidence for the belief that the inversion of cane-sugar takes place to any marked extent in the stomach under normal conditions. The starch, however, which has been subjected to the action of the saliva, still continues to be converted into maltose during the first fifteen to thirty minutes or even longer. Even though gastric juice is being secreted and though hydrochloric acid solutions with a strength of 0.3 per cent. will arrest the action of ptyalin, starch digestion continues for the reason that the acid combines with the proteids and is thus rendered inoperative and for the further reason that the food is largely retained in the extreme cardiac end of the stomach where the gastric juice is not abundant. After the above-mentioned period, free acid makes its appearance when salivary digestion ceases.

Action of Gastric Juice on Foods.—The action of gastric juice on proteids affords a key to its influence in the reduction of foods to the liquid or semiliquid condition. It is evident that it will be most active in the digestion of food consisting largely of proteid materials, such as meat, eggs, milk, etc. Meat is disintegrated first by the conversion of the proteids of the connective tissue, which have been more or less gelatinized by cooking, into peptones. The sarcolemma of the muscle-fibers which have been thus separated is in a similar manner attacked and converted into peptones. The true muscle or sarcous substance, consisting largely of myosin, undergoes a corresponding change. If the quantity of meat be not too large and the gastric juice be secreted in proper amount, it is possible that all the meat will be digested in the stomach. It is quite probable, however, that this is not the case and that a portion of the semidigested meat passes into the intestine, where its final solution is effected.

The white of egg, especially when slightly boiled, is much more readily digested than when raw or firmly coagulated by prolonged boiling. In either condition, however, the connective tissue is dissolved and peptonized, after which the native albumin undergoes the same change. The yolk of the egg consists largely of fat held in suspension by a proteid substance, vitellin, which is also capable of transformation into peptone.

Adipose tissue is similarly reduced. The proteids of the connective tissue and of the fat vesicles are dissolved and peptonized and the fat-drops set free.

Milk undergoes a peculiar change in composition before its proteid constituents can be transformed into peptones. The caseinogen in the presence of calcium salts is always in the soluble state. When acted on by the gastric juice, the caseinogen undergoes coagulation which consists in the formation of a solid compound, casein, and a soluble albumin. This change is due to the presence and activity of the ferment, rennin. The necessity for this change, however, is not apparent. The coagulated casein presents itself in the form of a flocculent curd, which is finer in human than in cow's milk, and hence more easily digestible. The casein is acidified by the hydrochloric acid and then converted by the pepsin into peptone.

Vegetables, though consisting of a woody or cellulose framework, undergo a partial disintegration in the stomach. When boiled and physically disintegrated by the teeth, the gastric juice is enabled to penetrate the framework and dissolve and peptonize the various proteid constituents. As a general rule, the vegetable proteids are more difficult of digestion than the animal proteids.

Duration of Gastric Digestion.—The length of time the food remains in the stomach and the relative digestibility of different articles of food were carefully studied by Dr. Beaumont on St. Martin, and though the results obtained by him may not be absolutely correct, viewed in the light of recent knowledge of the digestive process, yet in the main they have been corroborated in various ways. As a result of many observations Dr. Beaumont came to the conclusion that the average length of time an ordinary meal consisting of meat, bread, potatoes, etc., remained in the stomach undergoing digestion was about three and a half hours, the duration of the process, however, being increased when an excessive quantity of food was taken or the quantity and quality of the gastric juice impaired by abnormal conditions of the system. As soon as the food is liquefied by the gastric juice that portion not absorbed by the gastric vessels passes into the intestines, this continuing for two to three hours until the stomach is completely emptied. The relative digestibility of the different foods was also made the subject of many experiments by Dr. Beaumont. After repeating and verifying his observations made under varying conditions, he summed up his results in a table, of which the following is an abstract, in which the mode of preparation and the time required for the digestion of different foods are exhibited:

TABLE SHOWING DIGESTIBILITY OF VARIOUS ARTICLES OF FOOD

	Hours.	Minutes.
Eggs, whipped,	1	20
“ soft boiled,	3	..
“ hard boiled,	3	30
Oysters, raw,	2	55
“ stewed,	3	30
Lamb, broiled,	2	30
Veal, broiled,	4	..
Pork, roasted,	5	15
Beefsteak, broiled,	3	..
Turkey, roasted,	2	25
Chicken, boiled,	4	..
“ fricasseed,	2	45
Duck, roasted,	4	..
Soup, barley, boiled,	1	30
“ bean, “	3	..
“ chicken, “	3	..
“ mutton, “	3	30
Liver, beef, broiled,	2	..
Sausage,	3	20
Green corn, boiled,	3	45
Beans, “	2	30
Potatoes, roasted,	2	30
“ boiled,	3	30
Cabbage, “	4	30
Turnips, “	3	30
Beets, “	3	45
Parsnips, “	2	30

Movements of the Stomach.—During the period of gastric digestion the muscle walls of the stomach become the seat of a series of movements, peristaltic in character, which not only incorporate the gastric juice with the food, but also serve to eject the liquefied portions of the food into the small intestine.

The movements of the human stomach as described by Beaumont, as well as the movements of the dog's stomach as stated by different observers, are not in agreement in all respects, and are, moreover, open to question for the reason that they were not observed under strictly physiologic conditions. The more recent investigations of Cannon have thrown new light on this subject. By means of the Röntgen rays he has been enabled to study the movements in the living animal and under normal conditions. The animal (the cat) was fed with bread and milk, to which was added subnitrate of bismuth. This substance, being opaque, rendered the movements of the stomach walls visible on the fluorescent screen. With paper placed over the screen it was possible to sketch the changes in shape that the stomach undergoes at different periods of the digestive act. Some of these changes are represented in Fig. 82. The anatomic features of the cat stomach of interest in this connection are represented in Fig. 83.

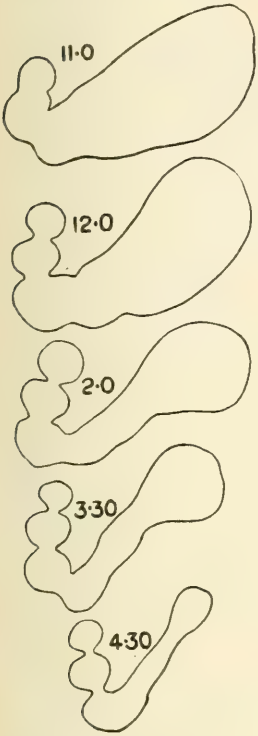


FIG. 82.—SHADOW SKETCHES OF THE OUTLINES OF THE STOMACH OF A CAT IMMEDIATELY AFTER A MEAL (11.0), AND AT VARIOUS INTERVALS AFTERWARD (AT 12.0, AT 2.0, 3.30, 4.30).—(*W. B. Cannon.*)

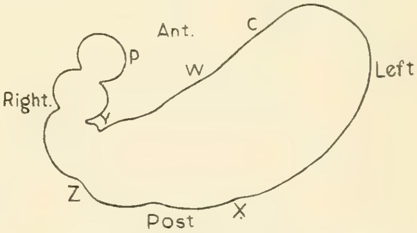


FIG. 83.—The cardiac portion is all that part to the left, as the stomach lies in the body, of *WX*. The cardia is at *C*. The pylorus is at *P*, and the pyloric portion is the part between *P* and *WX*. This has two divisions: the antrum, between *P* and *YZ*, and the pre-antral part, between *WX* and *YZ*. The lesser curvature is on the top of the outline between *C* and *P*, and the greater curvature between the same points along the lower border.—(*Amer. Jour. of Physiology, Cannon.*)

These investigations show that different portions of the stomach walls exhibit different forms of activity, which for convenience of description are separately described by Cannon as follows:

1. *The Movements of the Pyloric Part.*—Within five minutes after

a cat has finished a meal of bread there is visible near the duodenal end of the antrum a slight annular contraction which moves peristaltically to the pylorus; this is followed by several waves recurring at regular intervals. Two or three minutes after the first movement is seen, very slight constrictions appear near the middle of the stomach, and, pressing deeper into the greater curvature, course slowly toward the pyloric end. As new regions enter into constriction, the fibers just previously contracted become relaxed, so that there is a true moving wave, with a trough between two crests. When a wave swings round the bend in the pyloric part, the indentation made by it deepens; and as digestion goes on the antrum elongates and the constrictions running over it grow stronger, but, until the stomach is nearly empty, they do not entirely divide the cavity. After the antrum has lengthened, a wave takes about thirty-six seconds to move from the middle of the stomach to the pylorus. At all periods of digestion the waves recur at intervals of almost exactly ten seconds. It results from this rhythm that when one wave is just beginning several others are already running in order before it. Between the rings of constriction the stomach is bulged out, as shown in the various outlines in Fig. 82.

Movements of the Pyloric Sphincter.—During the first ten or fifteen minutes after the first constriction of the antrum the pylorus is tightly closed. After this period it opens at irregular intervals to permit the passage of liquefied food which is ejected by peristaltic waves for a distance of two or three centimeters into the duodenum. The frequency with which the pylorus opens depends apparently on the degree to which the food is softened. When the food is hard, the pylorus closes more tightly and remains closed a longer period than when it is soft.

The Activity of the Cardiac Portion.—As digestion proceeds, the pre-antral part of the stomach elongates and assumes the shape of a tube, which becomes the seat also of peristaltic constriction waves. As a result, some of the food is gradually forced into the antrum to succeed that which has been prepared and ejected into the duodenum. As the pre-antral tube is emptied of its contents the longitudinal and circular fibers of the fundus steadily contract and gradually force its contents into the tubular portion. This continues until the fundus is completely emptied. The changes in shape which the cardiac portion undergoes during digestion are represented in Fig. 82. The fundus acts as a reservoir for the food and forces out its contents a little at a time as the antral mechanism is ready to receive them. Since peristaltic movements are absent from the cardiac portion the food is not mixed with gastric juice, and therefore salivary digestion can continue for a considerable period. There is no evidence of a circulation of food in the stomach as usually described. On the contrary, the movement through the pre-antral tube and antrum is in general a progressive though an oscillating one. As the constriction waves rapidly pass over the food it is advanced toward the pyloric opening, but as this is closed the food is forced backward through the advancing constricted ring for a variable distance.

The effect of the constriction waves is to mix the food with the gastric juice, triturate and soften it. So soon as this is effected, the pylorus relaxes, when the advancing constriction wave expels it into the intestine. With its expulsion room is afforded for an additional quantity of food, and hence there is a general advance of the food mass toward the pylorus.

Though these observations were made on the cat, evidence is accumulating which goes to show that in human beings the walls of the stomach exhibit constriction waves which are similar in all respects to those above described.

The Nerve Mechanism of the Stomach.—In preceding paragraphs it was stated that during the period of gastric digestion the food is retained in the stomach because of the closure of the cardia (the esophago-gastric orifice) and of the pylorus (the gastro-duodenal orifice) both orifices being tightly closed by the tonic contraction of sphincter muscles; that both sphincters relax from time to time, the one to permit the entrance of food into the stomach for further digestion, the other to permit the exit of food into the intestine after its more or less complete digestion, after which in both instances the sphincters again contract and close the orifices; that the pyloric or antral muscles are vigorously active throughout the digestive period, triturating the food, mixing it with gastric juice, and finally driving it through the temporarily open pylorus into the intestine.

These separate but related groups of muscle-fibers, by reason of their endowments, and possibly by virtue of the presence of local nerve mechanisms, exhibit activities which are independent of the central nerve system. Thus the isolated stomach of the dog and of other animals as well, if kept warm and moist, will exhibit rhythmic movements for a period of time varying from an hour to an hour and a half. Though nerve-cells and nerve-fibers (Auerbach's plexus) are present in the walls of the stomach between the layers of muscle-fibers, it is not believed that they are the immediate sources of the stimulus to the contraction, though they may act as a coördinating mechanism. The stimulus in all probability develops in the muscle-fiber itself and is therefore myogenic in origin.

The *sphincter cardiæ* muscle surrounding the esophago-gastric orifice is always under normal conditions, tonically contracted and the orifice closed. This contraction is partly due to inherent causes as shown by the fact that it persists for from 24 hours to several days after division of all nerves distributed to it. The contraction may be so pronounced as to offer considerable resistance to the passage not only of food but even to the introduction of a sound into the stomach. (Cannon.) That the normal contraction is under the influence of the central nerve system is shown by the effects which follow stimulation of the peripheral end of the divided vagus. If it is stimulated with weak induced currents, the contraction is somewhat inhibited and the orifice enlarged; if it is stimulated with strong currents the contraction is markedly increased. Apparently there are in the vagus two sets of efferent nerve-fibers, one of which augments, while the other inhibits the contraction, and corresponding to the nerves there must be in the medulla oblongata two centers from which they arise, an augmentor and an inhibitor.

Observation has shown that at the beginning of each act of deglutition, there is an inhibition of the sphincter muscle, and if the acts follow each other in quick succession, the inhibition and relaxation are increased. With the passage of the food into the stomach the tonic contraction again supervenes. These effects also follow stimulation of the glossopharyngeal nerve which evidently carries nerve impulses to these centers. Whether the sphincter inhibition is the result of an inhibition of the center which maintains the tonus, or a stimulation of the inhibitor center, is uncertain.

The degree of activity also of both the pyloric sphincter and the antral muscles is modified by the central nerve system either in the way of inhibition or augmentation and in response to gastric stimulation. The nerves more especially concerned in the maintenance and regulation of the gastric contractions are the vagi and the splanchnics. The *afferent* fibers through which nerve impulses pass to the nerve centers are in all probability contained in the trunk of the vagus nerve; the *efferent* fibers through which nerve impulses from the centers reach the stomach, are contained partly in the trunk of the vagus and partly in the trunk of the splanchnic nerve.

If the vagus nerves are divided in the neck, there is a loss of muscle tonus though the contractions do not wholly disappear. Stimulation of the peripheral end of one divided vagus is followed by an augmentation in the vigor of the contraction of the antral muscles, an increase in the tone of the fundus muscles, as well as an increase in the contraction of the sphincter pylori and sphincter cardiæ. Though this is the usual result there may be a primary relaxation or inhibition of short duration of one or all of these structures before the augmentation occurs. May states that this was always the case in his experiments. A similar inhibition may be brought about reflexly by stimulation of the central end of a divided vagus. This result will not be produced if the opposite vagus has previously been divided. The vagi, therefore, contain both inhibitor and augmentor nerve-fibers for the gastric musculature.

Stimulation of the peripheral end of a divided splanchnic is followed by an inhibition of the peristalsis and a loss of tone. Morat, however, has observed a primary opposite effect. From these facts it would appear that the gastric muscles receive both inhibitor and augmentor fibers from two different sources.

The excitatory cause for the activity of this mechanism is doubtless connected with the chemic and mechanic stimulation by the gastric contents. The relaxation or inhibition of the sphincter pylori appears to be caused by the presence of free acid at the pylorus; its contraction, by the presence of acids in the duodenum. With their neutralization in the duodenum, their influence on the sphincter muscle is weakened after which it again becomes susceptible to the inhibitor influence of the acid within the stomach. It is probably for this reason that carbohydrates which do not absorb the acid are discharged from the stomach early; that the proteids which postpone the appearance of free acid are retained longer and that fats which check the secretion of gastric juice are discharged slowly (Cannon). It should be emphasized, however, that the relaxation and contraction of the pyloric sphincter, due to the action of free acid on the gastric and duodenal sides, respectively, can take place independently of the nerve system.

INTESTINAL DIGESTION.

The physical and chemic changes which the alimentary principles undergo in the small intestine, and which collectively constitute intestinal digestion, are probably more important and complex than those taking place in the stomach, for the food is, in this situation, subjected to the solvent action of the pancreatic and intestinal juices, as well as to the action of the bile, each of which exerts a transforming influence on one or more substances and still further prepares them for absorption into the blood.

To rightly appreciate the physiologic actions of the digestive juices poured into the intestine, the nature of the partially digested food as it comes from the stomach must be kept in mind. This consists of water, inorganic salts, acidified proteids, albumoses, peptones, starch, maltose, liquefied fat, saccharose, lactose, dextrose, cellulose, and the indigestible portion of meats, cereals, and fruits. Collectively they are known as chyme. As this acidified mass passes through the duodenum its contained acids excite a reflex secretion and discharge of the intestinal fluids: *e. g.*, pancreatic juice, bile, and intestinal juice. Inasmuch as these fluids are alkaline in reaction they exert a neutralizing and precipitating influence on various constituents of the chyme. As soon as this has taken place, gastric digestion ceases and those chemic changes are inaugurated which eventuate in the transformation of all the remaining undigested nutritive materials into absorbable and assimilable compounds which collectively constitute intestinal digestion.

THE SMALL INTESTINE.

The small intestine, in which this stage of digestion takes place, is a convoluted tube, measuring about seven meters in length and 3.5 cm. in diameter, and extending from the pyloric orifice of the stomach to the beginning of the large intestine.

The intestine consists of four coats: viz., serous, muscular, submucous, and mucous.

The *serous coat* is the most external and is formed by a reflection of the general peritoneal membrane. It is, however, wanting in the duodenal portion.

The *muscle coat,* situated just beneath the former, surrounds the entire intestine. It is composed of non-striated fibers which are more abundant and better developed in the upper than in the lower portions of the intestine. The muscle coat consists of two layers of fibers: (1) an external or longitudinal, and (2) an internal or circular layer. The longitudinal fibers are most marked at that border of the intestine free from peritoneal attachment, though they form a thin layer all over the intestine. The circular fibers are much more numerous, and completely encircle the intestine throughout its entire extent. It has been demonstrated that at the junction of the ileum and colon, and surrounding the orifice, the *ileo-colic,* common to both, the muscle-fibers are arranged in the form of, and play the part of, a sphincter muscle, which has been termed the *ileo-colic* sphincter. It is usually in a state of tonic contraction and regulates the passage of materials from the small into the large intestine, and possibly also in the reverse direction under special circumstances.

The *submucous coat* consists of areolar tissue and serves to unite the muscular with the mucous coat. A thin layer of muscle-fibers, the *muscularis mucosa,* is placed on its inner surface.

The *mucous coat* is soft and velvety in appearance and covered by a single layer of columnar epithelium. Its entire surface is covered with small conical projections termed villi. Throughout its entire extent, with the exception of the lower portion of the ileum and the duodenum, the mucous membrane presents a series of transverse folds—the valvulæ conniventes, or valves of Kirkring. These folds vary from one-fourth to half an inch in width and extend one-half to two-thirds of the distance around the interior of the bowel. Each valve consists of two layers of the mucous membrane permanently united by fibrous tissue. It is believed that the valves retard to some extent the passage of the food through the intestine and present a greater surface for absorption.

Blood-vessels, Nerves, and Lymphatics.—The blood-vessels, of the small intestine, which are very numerous, are derived mainly from the superior mesenteric artery. After penetrating the intestinal walls the smaller vessels ramify in the submucous coat and send branches to the muscle and mucous coats, supplying all their structures with blood. After circulating through the capillary vessels the blood is returned by small veins which subsequently unite to form the superior mesenteric vein, which, uniting with the splenic and gastric veins, forms the portal vein. The nerves are derived from the lower part of the solar plexus. The branches follow the blood-vessels and become associated with two plexuses, one (Auerbach's) lying between the muscle coats, the other (Meissner's) lying in the submucous coat. The lymphatics, which originate in the mucous and muscle coats, are very abundant. They unite to form those vessels seen in the mesentery and empty into the thoracic duct.

Intestinal Glands.—The gland apparatus of the intestine by which the intestinal juice is secreted consists of the duodenal (Brunner's) and the intestinal (Lieberkühn's) glands.

The *duodenal glands* are situated beneath the mucous membrane and open by a short wide duct on its free surface. They are racemose glands lined by nucleated epithelium. The secretion of these glands is clear, slightly viscid, and alkaline. Its chemic composition and function are unknown.

The *intestinal glands* or follicles are distributed throughout the entire mucous membrane in enormous numbers. They are formed mainly by an inversion of the mucous membrane and hence open on its free surface. Each tubule consists of a thin basement membrane lined by a layer of spheric epithelial cells, some of which undergo distention by mucin and become converted into mucous or goblet cells. The epithelial secreting cells consist of granular protoplasm containing a well-defined nucleus. The intestinal follicles constitute the apparatus which secretes the chief portion of the intestinal juice.

Intestinal Juice.—Owing to its admixture with other secretions and to the profound disturbance of the digestive function, caused by the establishment of intestinal fistulæ, this fluid has rarely been obtained in a state of purity or in quantities sufficient for accurate analyses or for experimental purposes. Its physiologic properties and functions are therefore imperfectly known. Various attempts have been made by physiologists, by the employment of different methods, to obtain this secretion. The method usually employed is that of Thiry and Vella. This consists in dividing the intestine at two places, about eight or ten inches apart, restoring the continuity of the intestine, and then uniting the two ends of the resected portion to the edges of two openings in the abdominal walls. The resected portion, being supplied with blood-vessels and nerves, maintains its nutrition and secretes a more or less normal juice.

When obtained from a dog under these circumstances the intestinal juice is watery in consistence, slightly opalescent, light yellow in color, alkaline in reaction, with a specific gravity of 1.010. Chemic analysis reveals the presence of proteids, mucin, and sodium carbonate.

The intestinal juice obtained by Tubbey and Manning from a small portion of the human intestine (ileum) was opalescent, occasionally brownish in color, alkaline, and had a specific gravity of 1.006. On the addition of hydrochloric acid, carbonic acid was given off, showing the presence of carbonates. It contained proteids and mucins.

PANCREAS.

The **pancreas** is a long flattened gland, situated deep in the abdominal cavity, lying just behind the stomach. It measures from six to eight inches in length, two and a half in breadth, and one in thickness. It is usually divided into a head, body, and tail. The head is directed to the right side and is embraced by the curved portion of the duodenum; the tail is directed to the left side and extends as far as the spleen (Fig. 84.) The pancreas communicates with the intestine by means of a duct. This duct commences at the tail and runs transversely through the body of the gland. As it approaches the head of the gland it gradually increases in size until it measures about one-tenth of an inch in diameter. It then curves downward and forward and opens into the duodenum. In its course through the gland it receives branches which enter it nearly at right angles. The pancreas is richly supplied with blood-vessels and nerves, the latter coming from the solar plexus.

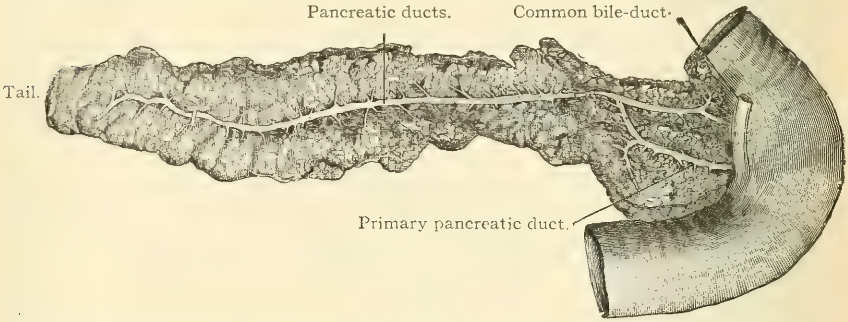


FIG. 84.—PANCREAS AND DUODENUM REMOVED FROM THE BODY AND SEEN FROM BEHIND. THE GLAND IS CUT TO SHOW THE DUCTS.—(*Landois and Stirling.*)

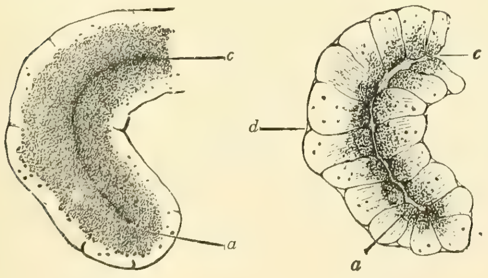


FIG. 85. FIG. 86.

ONE SACCULE OF THE PANCREAS OF THE RABBIT IN DIFFERENT STATES OF ACTIVITY. Fig. 85.—After a period of rest, in which case the outlines of the cells are indistinct and the inner zone—*i. e.*, the part of the cells (*a*) next the lumen (*c*)—is broad and filled with fine granules. Fig. 86.—After the gland has poured out its secretion, when the cell outlines (*d*) are clearer, the granular zone (*a*) is smaller, and the clear outer zone is wider.—(*Yeo's "Text-book of Physiology," after Kühne and Lea.*)

Histologic Structure.—In its structure the pancreas resembles the salivary glands. It consists of a connective-tissue framework which divides the gland tissue into lobules. Each lobule is composed of a number of acini or alveoli, more or less elongated or tubular in shape. Each acinus gives origin to a small duct which, uniting with adjoining ducts, forms the lobular duct, which becomes tributary to the main duct. The acinus is lined by a layer of cylindric epithelial cells characterized by a difference in structure between the central and peripheral ends (Fig. 85). The central end, that bordering the lumen of the acinus, is dark in appearance and filled with dark granules, while the peripheral end is clear and homogeneous. The relative depth of these two zones varies according to the functional activity of the gland. During the intervals of digestion the granular layer is very deep and occupies almost the entire cell; after active digestion the granular layer is very narrow, while the clear zone is largely increased in depth. The blood-vessels of the pancreas are arranged around the acini in a manner similar to that observed in the salivary glands. The ultimate terminations of the nerves in the epithelium are probably by means of the usual end-tufts.

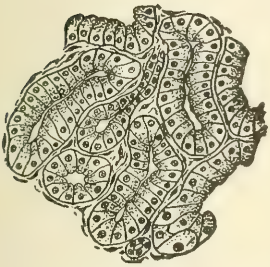


FIG. 87.—SECTION OF HUMAN PANCREAS, INCLUDING SEVERAL ACINI AND TWO DUCTS. THE CELLS PRESENT A CENTRAL GRANULAR AND A PERIPHERAL CLEAR ZONE.—(*Piersol.*)

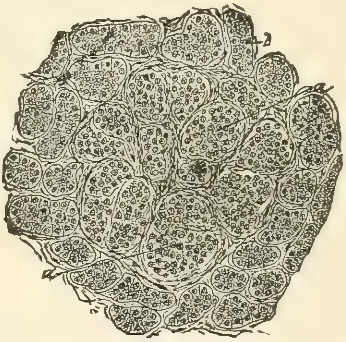


FIG. 88.—SECTION OF HUMAN PANCREAS SHOWING, *a*, *a*, ISLANDS OF LANGERHANS, AND *b*, THE USUAL ACINI.—(*Piersol*).

The Islands of Langerhans.—Throughout the body of the pancreas and especially in the outer extremity there are found between and among the acini collections of globular cells arranged in the form of rods or columns, separated from the acini and from one another by layers of connective tissue in which ramify large tortuous capillary blood-vessels. These columnar bodies, seen in cross-section in Fig. 88, have been named, after their discoverer, the islands of Langerhans.

Embryologic investigations have shown that these cells are outgrowths from the primitive acini, to which they remain attached for some time by means of a foot-stalk. This subsequently becomes constricted by the connective tissue and the cells become completely detached. The cells then assume the columnar arrangement, after which vascularization takes place.

From the fact that complete extirpation of the pancreas as well as its various diseases is followed by serious disturbances of the carbohydrate metabolism it has been suggested that the islands of Langerhans have a function separate and distinct from that of the glandular portion of the pancreas; that they secrete a specific material which partakes of the nature of an internal secretion which is absorbed by the blood circulating around them and carried to different tissues. The effect on the metabolism of the body which follows extirpation of the pancreas will be referred to in a subsequent chapter.

Pancreatic Juice.—The pancreatic juice may be obtained by introducing a silver cannula, through an opening in the abdominal wall, into the duct, and securing it by a ligature. In a short time the juice flows from the distal end of the cannula, when it can be collected. According to Bernard, normal juice can only be obtained during the first twenty-four hours. The juice obtained from a temporary fistula is clear, slightly opalescent, viscid, of a decidedly alkaline reaction, and has a specific gravity in the dog of 1.040. When cooled to 0° C., it assumes a gelatinous consistence. At 100° C. it completely coagulates. When obtained from a permanent fistula, the juice is watery and the solid constituents are very much diminished in amount.

The chemic composition of the pancreatic juice of the dog as determined by Schmidt is as follows: water, 900.76; organic matter, 90.44; inorganic salts, 8.80. Of the inorganic salts, sodium carbonate is probably the most essential, as it is this salt which gives to the juice its alkaline reaction.

Mode of Secretion.—The secretion of the juice is, in the rabbit and dog at least, almost continuous during a period of twenty-four hours after a single average meal, though the rate of flow varies considerably during this period. As soon as food enters the stomach the flow of the pancreatic juice begins and steadily increases in amount until about the third hour, when it reaches its maximum; after this period the flow diminishes until the sixth hour, when it again increases for about an hour. It then gradually diminishes until it ceases entirely. During the period of secretory activity the gland becomes red and vascular from a dilatation of the blood-vessels.

The discharge of the juice associated with the introduction of food into the stomach is brought about in all probability through the agency of the nerve system, though the exact mechanism is imperfectly understood. It is probable that impressions made on the terminal filaments of the pneumogastric nerve ascend to the medulla, whence impulses pass outward through vaso-motor and secretor nerves to the blood-vessels and secreting cells of the glands. Stimulation of the peripheral end of the divided vagus gives rise to increased secretion. Inasmuch as various agents, such as mineral and organic acids, placed on the duodenal mucous membrane excite the flow, it is quite probable that the passage of the acid contents of the stomach through the duodenum also acts as a powerful stimulus to the discharge of the juice. But as the secretion and discharge of the juice is excited by the same conditions after the division of all related nerves, other explanations were sought for. Bayliss and Starling made the discovery that the secretory activity of the pancreas is initiated and maintained by the action of a specific substance to which they have given the term *secretin.* This substance is developed in the duodenal glands out of a precursor, *prosecretin,* in consequence of the action of the acids in the chyme, after which it is carried by the blood-stream to the pancreas. An extract of the duodenal mucous membrane made with hydrochloric acid 0.4 per cent. and presumably containing secretin, when injected into the blood will evoke a profuse discharge of pancreatic juice. Hydrochloric acid alone will not have this effect. The total amount of pancreatic juice secreted in twenty-four hours has been only approximately determined; the estimates based upon the amount obtained from dogs vary from 175 to 800 grams.

Histologic Changes in the Cells during Secretory Activity.—Reference has already been made to the fact that the cells lining the acini consist of two zones: an outer one, clear and homogeneous; and an inner one, dark and granular. The position of the nucleus of the cell varies, being at one time in the outer, at another time in the inner, zone. If the pancreas be examined microscopically during the intervals of digestion, it will be observed that the inner zone is broad, highly granular, occupying nearly the entire cell, while the outer zone is narrow and clear. If, however, the gland be examined shortly after a period of active secretion, the reverse conditions will be observed; that is, the inner zone will be narrow, containing relatively few granules, while the outer zone will be clear and wide. This change in the cell has been witnessed in the pancreas of the living animal—rabbit—by Kühne and Lea. They observed that as soon as digestion set in, the granules of the broad inner zone began to pass toward the lumen of the acinus and to gradually disappear as the secretion was poured out, while the outer zone increased in width until almost the entire cell became clear and homogeneous. (See Fig. 86.) After secretion ceased the granules again made their appearance, the result, in all probability, of metabolic activity.

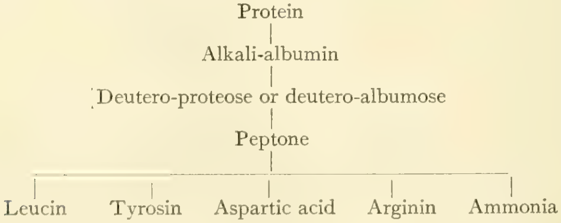
Physiologic Action of Pancreatic Juice.—Experimental investigations have demonstrated the fact that pancreatic juice is the most complex in its physiologic action of all the digestive fluids. In virtue of its contained enzymes, pancreatic juice acts:

1. On *starch.* When normal pancreatic juice or a glycerin extract of the gland is added to a solution of hydrated starch, the latter is speedily transformed into maltose, passing through the intermediate stage of dextrin. The process is in all respects similar to that observed in the digestion of starch by saliva. Pancreatic juice, however, is more energetic in this respect than saliva. The enzyme which effects this change is termed *amylopsin.* When the starch which escapes salivary digestion passes into the small intestine and mingles with pancreatic juice, it is very promptly converted into maltose by the action or in the presence of this enzyme.

2. On *protein.* When protein compounds are subjected to the action of pancreatic juice, they are transformed into peptones which do not differ in essential respects from those formed by gastric juice. The intermediate stages, however, are believed to be somewhat different. The enzyme which effects this change is termed *trypsin.*

When fibrin, for example, is added to trypsin in a solution rendered alkaline by sodium carbonate, it does not swell up and become translucent, as it does when treated with hydrochloric acid and pepsin. On the contrary, it becomes corroded on the surface, fragile, and in a short time undergoes solution. The first product is a compound termed alkali-albumin. After solution has taken place, various chemic changes are initiated which eventuate in the production of peptone and certain nitrogenized bodies, leucin, tyrosin, aspartic acid, etc. The intermediate stages in this process have not been satisfactorily determined. At no time during artificial pancreatic digestion is there any evidence of the presence of the primary proteoses (proto-albumose and hetero-albumose). The secondary proteoses (deutero-albumose) are usually present. It will be recalled that when the peptone of peptic digestion is subjected to the action of trypsin a portion of it is decomposed into leucin and tyrosin, while another portion presumably is not so decomposed, for which reason the latter was called *anti-* and the former, *hemi*-peptone. It is now believed that anti-peptone is not a peptone at all, but a compound termed *carnic acid*, which can be decomposed into simpler nitrogen-holding bodies such as leucin, tyrosin, arginin, etc.

The action of trypsin on proteins in an alkaline medium may be illustrated by the following scheme:



When the proteins which have escaped digestion in the stomach pass into the small intestine and mingle with the pancreatic juice, they are doubtless digested in the course of the intestinal canal, passing through the stages just described. As leucin and tyrosin are found in the intestine during digestion, it is probable that a portion of the peptone undergoes decomposition into these bodies; but as to the extent to which this takes place or in how far it is a necessary process under normal conditions is yet a subject of investigation. It is certain that it takes place when there is an excess of protein food or when for any reason digestion is prolonged or absorption is delayed.

While the view that the final stage in the digestion of proteins is the formation of peptones, which in due time are absorbed and synthetized into blood albumin, is generally accepted, there is some evidence that it is not wholly true, and that the final stage may be the formation of the nitrogen-holding compounds above mentioned; in other words, that the cleavage of the proteins is far more complete than has heretofore been assumed. Indeed it has been asserted that they are reduced, if not to their ultimate constituents, the amino- and diamino-acids, at least to one or more of the different polypeptid stages. Ever since the discovery by Cohnheim of the existence in the intestinal juice of a substance termed by him *erepsin*, which is capable of splitting proteoses and peptones into simple nitrogen-holding compounds, there has been slowly developing the idea that normally during intestinal digestion the proteoses and peptones are reduced by this agent to leucin, tyrosin, histidin, arginin, aspartic acid, etc., which in turn are absorbed and synthetized to blood or tissue albumin. The discovery by Vernon of erepsin in pancreatic juice lends further support to this view. Until more convincing evidence is furnished, however, it may be assumed that peptone represents the final stage in the digestion of proteins.

3. On *fat*. If pancreatic juice be added to a perfectly neutral fat—olein, palmitin, or stearin—and kept at a temperature of about 100° F. (38° C.), it will at the end of an hour or two be partially decomposed into glycerin and the particular fatty acid indicated by the name of the fat used—*e. g.*, oleic, palmitic, stearic. The oil will then exhibit an acid reaction. The reaction is represented in the following formula:

$$\underset{\text{Triolein.}}{C_3H_5(C_{18}H_{33}O_2)_3} + \underset{\text{Water.}}{3H_2O} = \underset{\text{Oleic Acid.}}{(C_{18}H_{34}O_2)_3} + \underset{\text{Glycerin.}}{C_3H_5(HO)_3}$$

If to this acidified oil there be added an alkali, *e. g.*, potassium or sodium carbonate, the latter will at once combine with the fatty acid to form a salt known as a soap. The reaction is expressed in the following equation:

$$\overset{\text{Sodium Carbonate.}}{Na_2CO_3} + \overset{\text{Oleic Acid.}}{C_{18}H_{34}O_2} = \overset{\text{Sodium Oleate.}}{Na_2OC_{18}H_{32}O_2} + \overset{\text{Carbonic Acid.}}{H_2CO_3}$$

Coincident with the formation of the soap the remaining neutral oil undergoes division into drops of microscopic size, which float in the soap solution, forming what has been termed an emulsion, which is white and creamy in appearance. The action of the pancreatic juice may then be said to consist in the cleavage of the neutral fats into fatty acids and glycerin, after which the formation of the soap and the division of the fat takes place spontaneously. The enzyme which produces the cleavage of the neutral fats has been termed *steapsin* or *lipase*. The extent to which the cleavage of the fat takes place in the intestine has not been definitely determined. There are some who think the amount is relatively small, while others consider that it is large, practically all of the fat undergoing this decomposition, with the formation of soap and glycerin prior to their absorption.

According to Pawlow, the relative amounts of the pancreatic enzymes produced are conditioned by the character and amounts of the food principles consumed. Thus, if chyme contains an excess of either starch, proteid, or fat, there is a corresponding increase in the amount of either amylopsin, trypsin, or steapsin produced. The pancreas apparently adapts its activities to the character of the food. Though it is probable that each enzyme is a derivative of a special zymogen, it is only positively known that this is the case with trypsin. This enzyme is a derivative of the zymogen, trypsinogen, the production of which is thought to be the special function of secretin. The pancreatic juice at the moment of its discharge into the intestine does not contain trypsin but trypsinogen. The transformation of the latter into the former is accomplished, according to Pawlow, by a special activating ferment secreted by the epithelium of the small intestine and termed *enterokinase.*

The rapidity with which pancreatic juice in the presence of bile and hydrochloric acid (under conditions such as are present in the duodenum) can develop sufficient fatty acid to form an emulsion was determined by Rachford to be two minutes. The activity of steapsin is thus shown to be very great.

Physiologic Action of the Intestinal Juice.—The part played by the intestinal juice in the digestive process is yet a subject of discussion, as the results obtained by different observers are in some respects contradictory, due to the fact that animals, including human beings, have been the subjects of experimentation. Notwithstanding the actions of saliva, gastric and pancreatic juice, there yet remain in the food saccharose, maltose, and lactose, three forms of sugar which are believed by most observers to be non-assimilable and therefore require some change before they can be absorbed and assimilated. An extract of the intestinal mucous membrane or the intestinal juice of a dog, added to a solution of saccharose, will in a very short time convert it into dextrose and levulose, which together constitute invert sugar. The enzyme by which this inversion is produced, though nothing definite is known as to its nature, has been termed *invertin* or *invertase.* Tubbey and Manning state that the human intestinal juice as obtained by them has the same action. In the case of intestinal fistulæ reported by Busch, which were supposed to be located in the upper third of the intestine, it was found that when saccharose was introduced into the lower opening, it was not inverted but appeared in the feces unchanged.

Maltose is also rapidly transformed into dextrose. Lactose appears to be unaffected by the pure juice. As it is non-assimilable it has been supposed to undergo conversion into dextrose and galactose while passing through the epithelial cells of the intestinal mucosa. In either case the transformation is brought about by two ferments known respectively as *maltase* and *lactase.*

Intestinal juice also has a slight diastatic action on starch.

THE LIVER.

The **liver** is a highly vascular conglomerate gland situated in the right hypochondriac region and connected with the intestine by a duct.

Inasmuch as the liver performs several functions related to both secretion and excretion, a consideration of its structure and its various functions will be deferred to a subsequent chapter. In this connection the bile, its physical properties and chemic composition in relation to the digestive process, will only be considered.

The **bile** is a product of the secretory activity of the liver cells. As it is poured into the intestine in man and most mammals at a point corresponding to the orifice of the pancreatic duct, and most abundantly at the time the food is passing through the duodenum, it is usually regarded as a digestive fluid possessing an influence favorable if not necessary to the completion of the general digestive process.

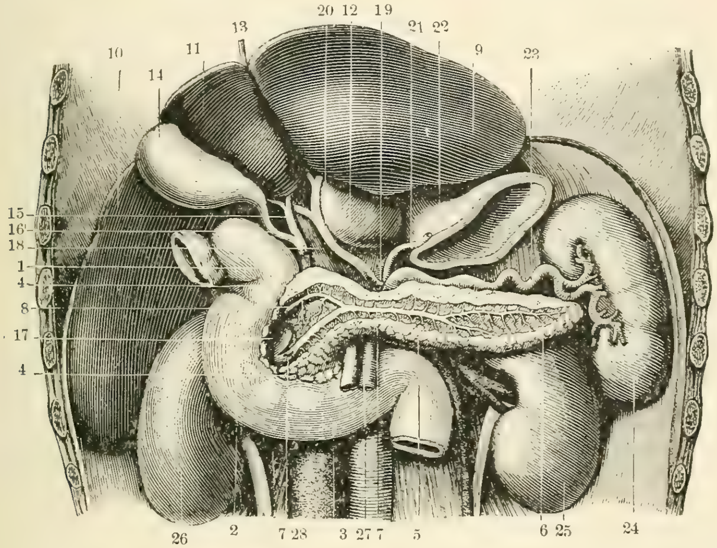


FIG. 89.—GALL-BLADDER, HEPATIC, CYSTIC, AND COMMON DUCTS. 1, 2, 3. Duodenum. 4, 4, 5, 6, 7, 7, 8. Pancreas and pancreatic ducts. 9, 10, 11, 12, 13. Liver. 14. Gall-bladder. 15. Hepatic duct. 16. Cystic duct. 17. Common duct. 18. Portal vein. 19. Branch from the celiac axis. 20. Hepatic artery. 21. Coronary artery of the stomach. 22. Cardiac portion of the stomach. 23. Splenic artery. 24. Spleen. 25. Left kidney. 26. Right kidney. 27. Superior mesenteric artery and vein. 28. Inferior vena cava.—(*Sappey.*)

Anatomic Relations of the Biliary Passages.—After its formation by the liver cells the bile is conveyed from the liver by the bile capillaries, which uniting finally from the main hepatic duct. This duct emerges from the liver at the transverse fissure. At a distance of about 5 centimeters it is joined by the cystic duct, the distal extremity of which expands into a pear-shaped reservoir, the *gall-bladder* in which the bile is temporarily stored (Fig. 89). The duct formed by the union of the hepatic and cystic ducts, the common bile-duct, passes downward and forward for a distance of about 7 centimeters, pierces the walls of the intestine and passes obliquely through its coats for about a centimeter and opens on the surface of a papilla in conjunction with the pancreatic duct. The walls of the biliary passages are composed of a mucous membrane internally, a fibrous and muscular coat externally. The termination of the common bile-duct is provided with a distinct band of circularly disposed muscle-fibers, which when in action completely close the orifice and prevent the discharge of bile. It may therefore be regarded as a true sphincter muscle. Small racemose glands are embedded in the mucous membrane of the main ducts.

Physical Properties and Chemic Composition of Bile.—The bile obtained directly from the liver through a fistulous opening in the hepatic duct is always thin and watery, while that obtained from the gall-bladder is more or less viscid from admixture with mucin, the degree of this viscidity depending on the length of time it remains in this reservoir. The specific gravity of human bile varies within normal limits from 1.010 to 1.020. The reaction is invariably alkaline in the human subject when first discharged from the liver, but may become neutral in the gall-bladder. The alkalinity depends on the presence of sodium carbonate and sodium phosphate. When fresh, it is inodorous; but it readily undergoes putrefactive changes, and soon becomes offensive. Its taste is decidedly bitter. When shaken with water, it becomes frothy—a condition which lasts for some time and which is due to the presence of mucin. In ox bile the mucin is replaced by a nucleo-proteid.

The color of bile obtained from the hepatic duct is variable, usually a shade between a greenish-yellow and a brownish-red. In different animals the color varies. In the herbivorous animals it is usually green; in the carnivorous animals it is orange or brown. In man it is green or a golden yellow. The colors are due to the presence of pigments. Microscopic examination does not show the presence of structural elements.

Human bile obtained from an accidental biliary fistula was shown by Jacobson to contain the following ingredients, viz.:

COMPOSITION OF HUMAN BILE.

Water,	977.40
Sodium glycocholate,	9.94
Sodium taurocholate,	a trace
Cholesterin,	0.54
Free fat,	0.10
Sodium palmitate and stearate,	1.36
Lecithin,	0.04
Other organic matters,	2.26
Sodium chlorid,	5.45
Potassium chlorid,	0.28
Sodium phosphate,	1.33
Calcium phosphate,	0.37
Sodium carbonate,	0.93
	1000.00

In this analysis the solid ingredients constitute 22.5 parts per 1000, of which two-thirds are organic and one-third inorganic. The amount of solid varies according to the animal from which the bile is obtained.

Sodium Glycocholate and Taurocholate.—Of the various ingredients of the bile none are more important than these two salts, usually known as the bile salts. The sodium glycocholate is found most abundantly in the bile of herbivora, the sodium taurocholate in the bile of the carnivora. These salts are compounds of sodium and glycocholic and taurocholic acids. When separated from the sodium, the acids will crystallize in the form of fine acicular needles. Under the influence of hydrating agents, such as dilute acids and alkalies, both acids will undergo cleavage into their respective components—*e. g.*, glycocoll and cholalic acid, taurine and cholalic acid. Glycocoll and taurine are crystallizable nitrogenized compounds known chemically as amido-acetic and amido-isothionic acids respectively. The bile salts are produced in the liver by a true act of secretion, as they are not found in any of the tissues and fluids of the body. After being discharged into the intestine they undergo chemic changes, after which they can no longer be recognized. In all probability they are reabsorbed into the blood and play some ulterior part in the nutrition of the body.

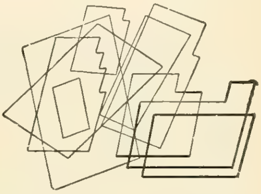


FIG. 90.—CHOLESTERIN CRYSTALS.—(*Landois and Stirling.*)

Cholesterin.—Cholesterin is a constant ingredient of bile, though it is not confined to this fluid, as its presence has been determined in the crystalline lens, blood-corpuscles, nerve-tissue, and various pathologic fluids. It is an organic non-nitrogenized substance resembling the fats in some particulars, but differing from them in not being capable of saponification with alkalies. It presents itself in the form of thin transparent rectangular crystals, insoluble in water but soluble in ether and boiling alcohol (Fig. 90). It is held in solution in bile by the bile salts. If they are deficient in amount, the cholesterin may pass out of solution, collect around some foreign matter, and form a gall-stone. Cholesterin is a product of the metabolism largely of nerve-tissue, from which it is absorbed by the blood, carried to the liver, and excreted. In the intestine it is converted into stercorin and discharged from the body in the feces.

Bilirubin, Biliverdin.—These two pigments impart to the bile its red and green colors respectively. Bilirubin is present in the bile of human beings and the carnivora, biliverdin in the bile of the herbivora. As the former pigment readily undergoes oxidation in the gall-bladder, giving rise to the latter pigment, almost any specimen of bile may present any shade of color between red and green. Bilirubin is regarded as a derivative of hematin, one of the cleavage products of hemoglobin, the coloring-matter of the blood. In the liver the hematin combines with water, loses its iron, and is changed to bilirubin. By continuous oxidation there are formed biliverdin, bilicyanin, and choletelin. After their discharge into the intestine the bile pigments are finally reduced to hydrobilirubin, which becomes one of the constituents of the feces. An oxidation of the bilirubin can be produced by nitroso-nitric acid. If this agent is added to a thin layer of bile on a porcelain surface, a series of colors will rapidly succeed one another, commencing with green and passing to blue, orange, purple, and yellow. This is the basis of the well-known test for bile pigments suggested by Gmelin.

Lecithin.—Lecithin is regarded, because of its physical properties and chemic composition, as a complex fat. When pure it presents itself generally as a white crystalline powder, though very frequently as a white waxy mass which is soluble in ether and alcohol. Its chemic formula is $C_{44}H_{90}NPO_9$. Lecithin is widely distributed throughout the body, being found in blood, lymph, red and white corpuscles, nerve-tissue, yolk of egg, semen, milk and bile. It is readily decomposed, yielding with various reagents glyco-phosphoric acid, a fat acid (stearic), and the alkaloid, cholin. Lecithin has been regarded as one of the decomposition products of nerve-tissue, removed from the blood by the liver and thus becoming one of the constituents of the bile in which it is held in solution by the bile salts.

The Mode of Secretion and Discharge of Bile.—The manner in which the bile flows from the liver into the main hepatic ducts, the variations in the rate of its discharge into the intestine, as well as the total quantity secreted daily, have been approximately determined by fistulous openings either in the hepatic ducts or in the gall-bladder. Although the liver presents some physiologic peculiarities, there is no reason to believe that the conditions of secretion therein are different from those in any other secretory organ, or that any other structure than the cell is engaged in this process. As shown by chemic analysis, the bile consists of compounds, some of which, like the bile salts, are formed in the liver cells, out of material furnished by the blood by a true act of secretion, while others, such as cholesterin and lecithin, principles of waste, are merely excreted from the blood to be finally eliminated from the body. The bile is thus a compound of both secretory and excretory principles.

The flow of bile from the liver is continuous but subject to considerable variation during the twenty-four hours. The introduction of food into the stomach at once causes a slight increase in the flow, but it is not until about two hours later that the amount secreted reaches its maximum; after this period it gradually decreases up to the eighth hour, but never entirely ceases. During the intervals of digestion though a small quantity passes into the intestine, the main portion is diverted into the gall-bladder, because of the closure of the common bile-duct by the sphincter muscle near its termination, where it is retained until required for digestive purposes. When acidulated food passes over the surface of the duodenum there is excited, through reflex action, a contraction of the muscle walls of the gall-bladder and ducts, a relaxation of the sphincter, and a gush of bile into the intestine, the discharge continuing intermittently until digestion ceases and the intestine is emptied of its contents.

The storage and the discharge of bile, brought about by the alternate contraction and relaxation of the muscle walls of the gall-bladder and of the sphincter is regulated by the nerve system. As the result of his experiments Doyon concludes, that during the intervals of intestinal digestion the vagus nerve is carrying nerve impulses which on the one hand augment the contraction of the sphincter and inhibit the contraction of the walls of the gall-bladder, thus establishing the conditions for the storage of bile; but when intestinal digestion is inaugurated the splanchnic nerve carries nerve impulses which inhibit the sphincter and augment the contraction of the walls of the gall-bladder, thus establishing the condition for the discharge of the bile.

The total quantity of bile secreted daily has been estimated to be from 500 to 800 grams.

Physiologic Action of Bile.—Notwithstanding our knowledge of the complex composition of bile, the quantity discharged daily, and the time and place of its discharge, its exact relation to the digestive process has not been fully determined. No specific action can be attributed to it. It has but a slight, if any, diastatic action on starch. It is without influence on proteins or on fats directly. But indirectly and by virtue of the bile salts it contains, it plays an important part in increasing the action of the pancreatic enzymes. Thus the amylolytic power of the pancreatic juice is almost doubled and the same is true for its proteolytic power, while its fat-splitting power is tripled. The bile salts also dissolve insoluble soaps which may be formed during digestion.

Bile thus favors the digestion of fat. If it be excluded from the intestine there is found in the feces from 22 to 58 per cent. of the ingested fats. At the same time the chyle, instead of presenting the usual white creamy appearance, is thin and slightly yellow. The manner in which the bile promotes fat digestion is yet a subject of investigation. If all the fat is converted into fatty acid and glycerin, with the formation of soaps, as seems probable, the action of the bile becomes more apparent from the fact, already stated, that it dissolves and holds in solution the soaps so formed which would be necessary to their absorption by the epithelial cells. As an aid to digestion the bile has been regarded as important, for the reason that its entrance into the intestine is attended by a neutralization and precipitation of the proteins which have not been fully digested and are yet in the stage of acid-albumin. In this way gastric digestion is arrested and the foods are prepared for intestinal digestion.

Though bile possesses no antiseptic properties outside the body, itself undergoing putrefactive changes very rapidly, it has been believed that in the intestine it in some way prevents or retards putrefactive changes in the food. There can be no doubt that if the bile be prevented from entering the intestine there is an increase in the formation of gases and other products which impart to the feces certain characteristics which are indicative of putrefaction. As to the manner in which bile retards this process nothing definite can be stated.

Bile has been supposed to be a stimulant to the peristaltic movements of the intestine, inasmuch as these movements diminish when bile is diverted from the intestine.

Though no definite nor specific action on any of the different classes of food principles can be attributed to the bile, there is abundant evidence to show that its presence in the alimentary canal during digestion is essential to the maintenance of the nutrition of the body. That the bile as a whole, or at least part of its constituents, favorably influences digestion and general nutrition is evident from the phenomena which follow its total exclusion from the intestine, as when the common bile-duct is ligated and a fistula of the gall-bladder is established. The following phenomena were observed in a young dog so prepared by Professor Flint. During the first five days succeeding the operation the abdomen was tumid and there was some rumbling in the bowels. Though the animal ate every day, the discharge of fecal matter became infrequent, the matter passed being grayish in color and highly offensive. After two weeks the alvine discharges took place three and four times daily. For four days the weight remained normal; afterward it began to diminish, and from this time the animal continued to lose strength and weight until its death, thirty-eight days after the operation. Ten days after the operation the appetite, which had been very good, increased, but did not become ravenous until a few days before death. The animal usually ate from a pound to a pound and a half of beef-heart daily, always refusing fat. There was an absence at all times of jaundice, fetor of the breath, and falling of the hair. Post-mortem examination showed that the bile-duct was obliterated, and there was no evidence that any bile could have passed into the intestine. The results of this and similar cases go to show that that portion of the bile which is secretory in character is essential to digestion and the nutrition of the body—that, though large quantities of food are consumed, progressive diminution of weight takes place until nearly 40 per cent. of the body is consumed. In some instances the breath becomes fetid and there is a falling of the hair, showing some profound disturbance of the general nutritive process.

The Movements of the Intestine.—The movements of the intestine have been studied by means of the Röntgen rays by Cannon. The method adopted was to mix with the food, subnitrate of bismuth, which being opaque rendered the movements of the intestinal contents and thereby the movements of the intestinal walls visible, on the fluorescent screen. These investigations revealed the presence of two forms of activity, one of which is more or less stationary and due to rhythmic contraction of circular muscle-fibers, the other progressive, passing from above downward and due to the contraction of circular and longitudinal muscle-fibers. The former activity, which is by far the more common, results in a division of the intestinal contents into small segments and for this reason was termed by Cannon, rhythmic segmentation; the latter activity is the well-known peristaltic wave.

After bands of circular muscle-fibers, situated at variable distances one from another, contract and divide a mass of food into segments, they at once relax and are followed by contraction of other bands in the segments of the intestines overlying the segments of food. The result is again a division of the food into two new segments (Fig. 91). The lower half of each segment then unites with the upper half of the segment below to commingle with it and expose new surfaces of the food mass to contact with the actively absorbing mucosa. The continual repetition of this process results in a thorough mixing of the food with the digestive juices. From the manner in which these contractions make their appearance it would seem that the mere presence of a segment in the lumen of the intestine is sufficient to excite the overlying fibers to activity.

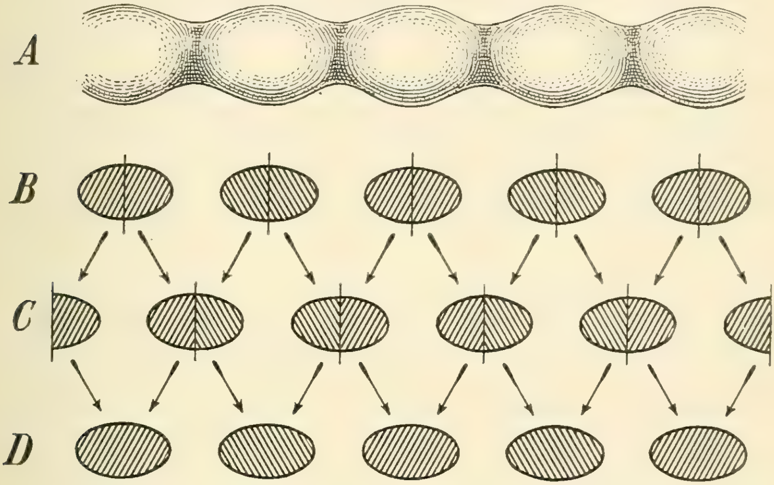


Fig. 91.—The Divisive or Segmenting Movements of the Small Intestine. *A*, surface view of a portion of the intestine, showing six constrictions which divide the contents into five segments, as shown in *B*; as these constrictions pass away new ones come in between them and divide each segment of the contents into two, the adjoining halves of neighboring segments fusing to make the new segments shown in *C*. Repetition of this process results in the condition shown in *D*. (*Modified, After Hough and Sedgewick, "The Human Mechanism."*)

In certain regions of the intestine rhythmic segmentation may continue for half to three-quarters of an hour without moving the food forward to any marked extent. In the cat the segmentation may proceed at the rate of thirty divisions a minute.

Bayliss and Starling state, from observations made on the exposed intestine of a dog, that in addition to the usual peristaltic movement the intestinal coils exhibit a swaying or pendulum movement accompanied by slight waves of contraction which may arise apparently at any point and pass down the intestine. These contractions may occur from ten to twelve times a minute and travel at a rate varying from two to five centimeters a second. In how far this movement represents the normal movement as it takes place under physiologic conditions and as observed by Cannon, remains for further investigators to decide.

After the food has been prepared by the process above described, it is then slowly carried downward by what is known as the vermicular or peristaltic wave. This wave is characterized by a contraction of the circular fibers behind a bolus and a relaxation of the fibers in advance of it. The result is a movement forward of the bolus, and as it moves it is followed by a ring of constriction and preceded by a ring of relaxation or inhibition. The rate of movement of the peristaltic wave is extremely slow.

The Nerve Mechanism of the Intestine.—The causes of these two forms of intestinal activity, rhythmic segmentation or pendulum movement and peristalsis, have been the subject of much investigation. Because of the presence of a network or plexus (Auerbach's and Meissner's) of nerve-cells and nerve-fibers in the walls of the intestines and in close relation to the muscle cells, and because of the fact that the intestines will contract for some time after removal from the body of the animal, it has been difficult to decide whether the contractions are of myogenic or neurogenic origin.

As the rhythmic contractions continue, though the peristaltic are abolished by the introduction of nicotin into the blood, an agent which temporarily paralyses peripheral nerve-cells, it was concluded by Bayliss and Starling that the rhythmic contractions are of myogenic origin and propagated from fiber to fiber and that the peristaltic contractions are reflex in character, the coördination being carried out by the local nerve mechanisms and initiated by stimulation of the intestine. Whether this is the case or not, the general contractions of the intestine are augmented and inhibited by the central nerve system through the vagus and splanchnic nerves.

Stimulation of the vagus is followed by an augmentation of the contraction, though not infrequently there is a primary inhibition of short duration. Stimulation of the splanchnic is followed by a relaxation or inhibition of the contraction, though according to some observers there is at times an opposite effect.

The Large Intestine.—The large intestine is that portion of the alimentary canal situated between the termination of the ileum and the anus. It varies in length from four and a half to five feet, in diameter from one and a half to two and a half inches. It is divided into the cecum, the colon (subdivided into an ascending, transverse, and descending portion, including the sigmoid flexure), and the rectum.

The cecum is situated in the right iliac fossa. It is that dilated portion of the large intestine below the orifice of the small intestine. The posterior and inner wall presents a small opening which leads into a narrow round process about four inches in length—the vermiform appendix. The opening of the small intestine into the cecum is narrow and elongated and bordered by two folds of mucous membrane strengthened by fibrous and muscle-tissue. These folds constitute the so-called ileo-cecal valve. When the cecum is distended the margins of these folds are approximated and effectually prevent the return of material into the small intestine.

The closure of this opening is now attributed to a sphincter muscle —the ileo-colic—the action of which is regulated by the nerve system.

The colon ascends to the under surface of the liver, where it bends at a right angle, crosses the abdominal cavity to the spleen, bends again, and descends to the left iliac fossa. At this point it turns upon itself to form the sigmoid flexure. The rectum is a dilated pouch, situated within the true pelvis. It measures from 15 to 18 centimeters in length. Within an inch of its termination at the anus it presents a constriction formed by a circular band of muscle-fibers known as the internal sphincter. The margin of the anus is also surrounded by bands of muscle-fibers known collectively as the external sphincter.

The walls of the large intestine consist of three coats: viz., serous, muscular, and mucous.

The *serous* is a reflection of the general peritoneal membrane.

The *muscle* is composed of both longitudinal and circular fibers. The longitudinal fibers are collected into three narrow bands which are situated at points equidistant from one another. At the rectum they spread out so as to completely surround it. As the longitudinal bands are shorter than the intestine itself, its surface becomes sacculated, each sac being partially separated from adjoining sacs by narrow constrictions. The circular fibers are arranged in the form of a thin layer over the entire intestine. Between the sacculi, however, they are more closely arranged. In the rectum they are well developed, and at a point an inch above the anus they form, as stated above, the internal sphincter.

The *mucous membrane* of the large intestine possesses neither villi nor valvulæ conniventes. It contains a large number of tubules consisting of a basement membrane lined by columnar epithelium. They resemble the follicles of Lieberkühn. The secretion of these glands is thick and viscid and contains a large quantity of mucin.

Contents of the Large Intestine.—As a result of the actions of saliva, of gastric, intestinal, and pancreatic juice, and of the bile, the food is disintegrated and liquefied. The nutritive principles, proteid, starches, sugars, and fats, undergo chemic changes and are transformed into peptones, dextrose, soap and glycerin, fatty acids, under which forms they are absorbed. After the more or less complete digestion and absorption of these nutritive substances the residue of the food, comprising the indigestible and undigested matter, passes out of the small intestine into the large intestine and forms a portion of its contents. This residue consists of the hard parts of the cereals, vegetable seeds, cellulose, etc., the quantity and variety of which depend on the nature of the food. These substances, passing into the large intestine along with the excrementitious matter of the bile, become incorporated with the mucous secretions and assist in the formation of the feces. Under the influence of a peristaltic movement similar to that witnessed in the small intestine, all this excrementitious matter, deprived by absorption of the excess of its contained water and nutritive material, is gradually carried downward to the sigmoid flexure, where it accumulates prior to its extrusion from the body.

The effects of the peristaltic waves are to some extent interfered with by anti-peristaltic waves which beginning in the transverse colon run toward and to the cecum. An anti-peristaltic wave occurs in the cat about every fifteen minutes and lasts for about five minutes. The intestinal contents are thereby driven back toward the cecum. The effect is a still further admixture with the secretions and exposure to the absorbing mucosa. There is some evidence also that the anti-peristaltic wave may force some of the liquefied contents through the ileocolic opening into the small intestine because of the relaxation of the sphincter muscle.

Intestinal Fermentation.—Owing to the favorable conditions in the intestine for fermentative and putrefactive processes—*e. g.*, heat, moisture, oxygen, and the presence of various microörganisms—the food, when consumed in excessive quantity or when acted on by defective secretions, undergoes a series of decomposition changes which are attended by the production of gases and various chemic compounds. Dextrose and maltose are partially reduced to lactic acid; this to butyric acid, carbon dioxid, and hydrogen. Fats are reduced to glycerol and fatty acids, the glycerol, according to the organisms present, yields succinic acid, carbon dioxid, and hydrogen. The proteids under the prolonged action of the pancreatic juice are decomposed, with the production of leucin and tyrosin. These crystalline compounds are in turn reduced to simpler forms. The former yields valerianic acid, ammonia, and carbon dioxid; the latter gives rise to *indol*, which is the antecedent of indican, found in the urine. Skatol, another derivative of the proteid molecule, due to bacterial action, gives the characteristic odor to the feces.

Feces.—The feces consist of water, mucin, the indigestible residue of the food, decomposition products, and inorganic salts. The consistency of the fecal matter varies from fluid to semifluid, depending largely on the length of time it remains in the intestine and the extent to which absorption of its watery portion has taken place. The odor is due to the presence of sulphuretted hydrogen and skatol. The color is due partly to the altered coloring-matter of the bile, *hydrobilirubin* or *stercobilin*, and partly to the character of the food. The total quantity discharged daily varies from four to six ounces.

Defecation.—Defecation is the final act of the digestive process and consists in the expulsion of the indigestible residue of the food from the intestine. This act usually takes place in the human being but once in twenty-four hours, as the diet contains but a minimum quantity of indigestible matter. Previous to their expulsion the feces which have accumulated in the sigmoid flexure must pass downward into the rectum. In so doing they develop the sensation which leads to the act of defecation. The descent of the feces is accomplished by the peristaltic contraction of the intestinal wall. Coincident with the passage of the feces into the rectum there is a relaxation of the sphincter muscles and a contraction of the longitudinal and circular muscular fibers, in consequence of which the feces are expelled. These complex muscular actions are also aided by the voluntary contractions of the diaphragm and abdominal muscles.

Nerve Mechanism of Defecation.—The act of defecation is primarily reflex, though somewhat influenced by voluntary efforts. Under normal conditions the sphincter muscles governing the anal orifice are firmly contracted, thus preventing the escape of gases or semisolid matter. This tonic contraction is maintained by a nerve-center located in the lumbar region of the spinal cord. The circular and longitudinal muscle-fibers of the rectum are at the same time in a relaxed condition. When the desire to evacuate the bowels is experienced, the impressions made by the feces on the afferent nerves of the rectal mucous membrane develop nerve impulses, which transmitted to the rectal center and to the brain, influence in one direction or another, their activities. If the act of defecation is to take place there is an inhibition of the contraction of the sphincter ani muscles and an augmentation of the contraction of the rectal muscles. In their expulsive efforts, these latter muscles are assisted by the contraction of the diaphragm, abdominal and other muscles. After the expulsion of the feces there is a return to the former condition, viz., a relaxation of the rectal muscles and a contraction of the sphincters.

If the act is to be suppressed, the controlling influence of the rectal or sphincter center is strengthened and the reflex mechanism for a while held in abeyance.

The exact course of the afferent and efferent nerves concerned in this reflex is yet a subject of investigation.

The nerve-supply for the circular and longitudinal muscles of the lower part of the colon and rectum varies somewhat in different animals, though it is usually derived from the second, third, and fourth lumbar and the second and third sacral or pelvic nerves.

The lumbar nerves pass into and through the sympathetic chain and thence to the inferior mesenteric ganglion, around the cells of which most of the nerves arborize. From this ganglion nerve-fibers pass to both the circular and longitudinal fibers.

The sacral or pelvic nerves pass to the hypogastric plexus and are ultimately connected with ganglion cells, which in turn send fibers to both the longitudinal and circular fibers. The explanation of the action of this complex mechanism is a subject of discussion because of the want of agreement in the results that follow stimulation of these nerves.

CHAPTER XI.

ABSORPTION.

Absorption is the process by which nutritive material is transferred from the tissues, from the serous cavities, and from the mucous surfaces of the body, into the blood. The most important of these surfaces, especially in its relation to the formation of blood, is the mucous surface of the alimentary canal, for it is from this organ that the new materials are derived which maintain the quantity and quality of the blood. The absorption of material from the interstices of the tissues and from the serous cavities may be regarded as an act of resorption, or a return to the blood of liquid nutritive material which has escaped through the walls of the capillary blood-vessels for purposes of nutrition, and which, if not returned, would lead to an accumulation and the development of edematous conditions.

The anatomic mechanisms involved in the absorptive process are, primarily, the *tissue* or *lymph-spaces*, the *lymph-* and *blood-capillaries;* secondarily, the *lymph-vessels* and the *veins.*

Tissue or Lymph-spaces; Lymph-capillaries.—Everywhere throughout the body, in the connective-tissue system and in the interstices of the several structures of which an organ is composed, are found spaces or clefts of irregular shape and size, determined largely by the structure of the organ in which they are found, which have been termed tissue or lymph-spaces, from the fact that they contain a clear fluid, the lymph. These spaces are devoid for the most part of any endothelial lining, but as they communicate more or less freely one with another, there is a circulation of lymph through them and around the islets of tissue (Fig. 93). In addition to the connective-tissue lymph-spaces, different observers have described special spaces or clefts in organs such as the kidney, liver, spleen, testicle, and in all secreting glands between their basement membrane and the surrounding blood-vessels, all of which contain a greater or less quantity of lymph. Within the brain, spinal cord, bone, and other tissues it has been shown that the smallest blood-vessels and capillaries are bounded and limited by a cylindrical sheath containing lymph, which is known as a perivascular lymph-space. A similar sheath surrounds the smallest nerve-bundles and fibers, enclosing a perineural lymph-space. The large serous cavities of the body, pleural, peritoneal, pericardial, etc., are also to be regarded as lymph-spaces. The surfaces of these cavities, however, are covered with a layer of endothelial cells with sinuous margins. At intervals between these cells are to be found small free openings which have received the name of *stomata.*

The **lymph-capillaries** in which the lymph-vessels proper take their origin are arranged in the form of plexuses of quite irregular shape. In most situations they are intimately interwoven with the blood-vessels, from which they can be readily distinguished by their larger caliber and irregular expansions. The wall of the lymph-capillary is formed by a single layer of endothelial cells with characteristic sinuous outlines. These capillaries anastomose very freely one with another and communicate, on the one hand, with the lymph-spaces and on the other with the lymph-vessels proper. As the shape, size, etc., of both lymph-spaces and capillaries are determined largely by the nature of the tissue in which they are found, it is not always possible to separate one from the other. Their function, however, may be regarded as similar: viz., the reception and collection of the lymph which has transuded through the walls of the blood-vessels and its transmission onward into the regular lymph-vessels.

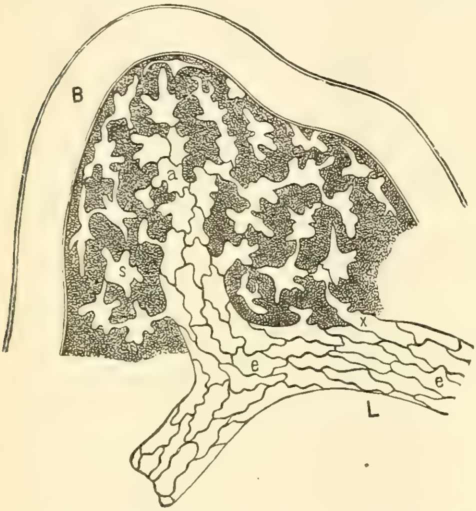


Fig. 93.—Origin of Lymphatics from the Central Tendon of the Diaphragm Stained with Nitrate of Silver. *s*. The lymph-spaces and lymph-canals, communicating at *x* with the lymphatics. *a*. Origin of the lymphatics by the confluence of several juice canals. B. Capillary blood-vessel.—(*Landois and Stirling.*)

The **blood-capillaries** not only permit of a transudation of the liquid nutritive material from the blood through their delicate walls, but are also engaged, if not in the reabsorption of a portion of this transudate, at least in the absorption of waste products resulting from tissue metabolism.

Lymph-vessels.—The lymph-vessels constitute a system of minute, delicate, transparent vessels found in nearly all the organs and tissues of the body, and take their origin from the lymph-capillaries and spaces above described (Figs. 94 and 95.) From their origin they gradually converge toward the trunk of the body, and finally empty into the thoracic duct. In their course they anastomose very freely with adjoining vessels. The diameter of a lymph-vessel varies from 1 to 2 mm. After the lymphatics have emerged from the lymph-capillaries they acquire three distinct coats, each of which possesses definite histologic features.

The *internal coat* is composed of a delicate lamina of longitudinally disposed elastic fibers covered with a layer of flattened nucleated endothelial cells with wavy outlines.

The *middle coat* consists of white fibrous tissue arranged longitudinally and of non-striated muscle and elastic fibers arranged transversely.

The *external coat* consists of practically the same structures, though the muscle-fibers are longitudinally disposed.

The lymphatics are provided with valves which are so numerous and located at such short intervals as to give the vessels a beaded appearance. These valves are arranged in pairs and consist of two semilunar folds with their concavities directed toward the larger vessels. They are formed by a reduplication of the lining membrane, which is strengthened by fibrous tissue derived from the middle coat.

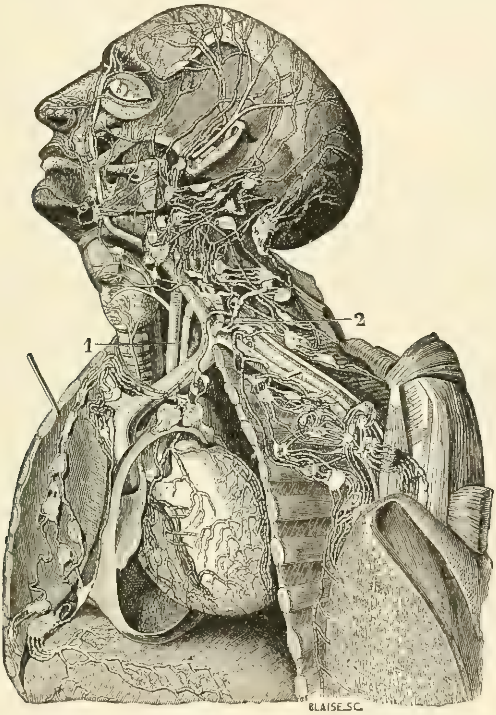


FIG. 94.—LYMPH-VESSELS AND LYMPH-GLANDS OF THE HEAD AND NECK.—(*From Gould's Dictionary.*)

Lymph-glands.—In their course toward the thoracic duct the lymph-vessels pass through a number of small lenticular bodies termed lymph-glands. These are exceedingly abundant in some situations, as the cervical, axillary, and inguinal regions, and the abdominal cavity. As the lymph-vessels approach a gland they divide into a number of branches before entering it, known as the afferent vessels. From the opposite side of the gland the lymphatics again emerge as efferent vessels to unite to form larger trunks. A section of a gland shows that it consists of an outer dense cortical and an inner soft pulpy medullary portion. Each gland is covered externally by a dense membrane of fibrous tissue containing in its meshes non-striated muscle-fibers. From the inner surface of this membrane there pass inward septa of connective tissue which, as they converge toward the center of the gland, divide the outer zone of the gland into small conical compartments or alveoli. When the septa reach the medullary portion, they subdivide and form bands or cords which interlace in every direction and constitute a loose meshwork the spaces of which communicate with one another and with the alveoli (Fig. 96). Within the meshes of this framework the proper gland substance is contained. In the cortical compartments it is moulded into pear-shaped masses; in the medullary meshwork it assumes the form of rounded cords which are connected with one another. In both regions, however, it is separated from the septa by a space termed a *lymph sinus*, through which the lymph flows as it passes through the gland. The lymph sinus is crossed by a network of retiform connective tissue which offers considerable resistance to the passage of the lymph. The gland substance consists also of a framework of retiform connective tissue in the meshes of which large numbers of lymph-corpuscles are contained. The gland substance is separated from the lymph sinus by a dense layer of a reticulum, which, however, does not prevent lymph and even corpuscles from passing through it into the lymph sinus.

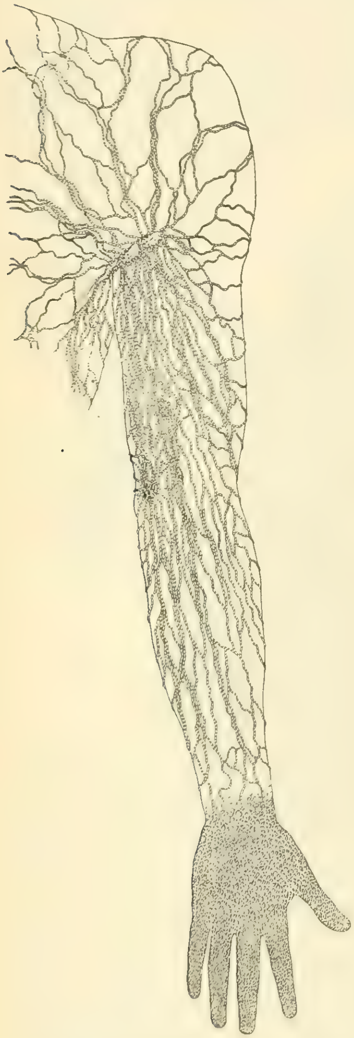


FIG. 95. LYMPH-VESSELS OF THE ARM.—(*Deaver.*)

The lymph-glands are abundantly supplied with blood-vessels. The arteries enter the gland at the hilum, penetrate into the medullary substance, and terminate in a fine capillary plexus which is supported by the connective tissue. The veins arising from this plexus leave the gland also at the hilum.

The lymph-vessels which enter a gland first ramify in the investing membrane and then open directly into the lymph sinus. The vessels which leave the gland are also in communication with the sinus. After the lymphatics enter the gland they lose their external and middle coats, retaining only the internal or endothelial coat, which lines the inner surface of the lymph sinus. The current of lymph, therefore, is from the afferent vessels through the lymph sinus into the efferent vessels. In addition to this primary current, there is a secondary current flowing from the capillary blood-vessels outward and into the sinus, which carries with it large numbers of lymph-corpuscles. It is quite probable that the movement of the lymph through this complicated system of passages is aided by the contraction of the muscle-fibers in the capsule of the gland.

The lymph-corpuscles or lymphocytes originate for the most part in the gland substance of the cortical alveoli. In this situation there are groups of cells, so-called germ centers, which divide very rapidly by mitosis and give rise constantly to groups of young cells which soon find their way into the lymph stream.

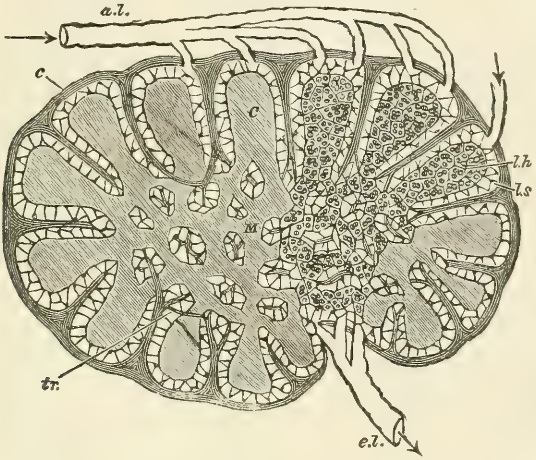


FIG. 96.—DIAGRAMMATIC SECTION OF A LYMPH-GLAND. *a. l.*, Afferent, *e. l.*, efferent lymphatics. C. Cortical substance. M. Reticular cords of medulla. *l. s.* Lymph sinus. *c.* Capsule, with trabeculæ, *tr.*—(*Landois and Stirling.*)

The Thoracic Duct.—The thoracic duct is the general trunk of the lymph system, into which the vessels of the lower extremities, of the abdominal organs, of the trunk, of the left arm, and of the left side of the head empty their contents. It is about fifty centimeters in length and four millimeters in diameter. It extends upward from the third lumbar vertebra along the vertebral column to the seventh cervical vertebra, where it empties into the venous system at the *junction of the internal jugular* and *subclavian veins* on the *left* side. The thoracic duct wall has the same general structure as the wall of the lymph-vessel: viz., an internal or endothelial; a middle elastic and muscular; an external or fibrous. It is also provided with numerous valves.

The lymph-vessels of the right side of the head, of the right arm, and a portion of the right ride of the trunk terminate in the *right thoracic duct*, which is about 25 to 30 mm. in length and which empties into the venous system at the junction of the internal jugular and subclavian veins on the right side. The general arrangement of the lymphatic system is diagrammatically shown in Fig. 97.

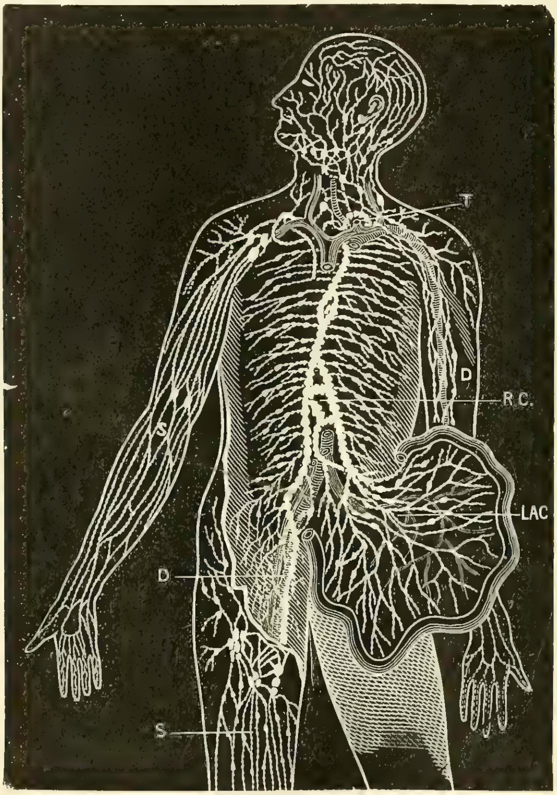


Fig. 97.—Diagram Showing the Course of the Main Trunks of the Absorbent System. The lymphatics of lower extremities (D) meet the lacteals of intestines (LAC) at the receptaculum chyli (RC), where the thoracic duct begins. The superficial vessels are shown in the diagram on the right arm and leg (S), and the deeper ones on the arm to the left (D). The glands are here and there shown in groups. The small right duct opens into the veins on the right side. The thoracic duct opens into the union of the great veins of the left side of the neck (T).—(*Yeo's "Text-book of Physiology."*)

LYMPH.

Lymph is the clear fluid found within the tissue spaces and within the lymph-vessels. Inasmuch as there are reasons for the view that lymph varies in composition, as well as in function, in these different regions it will be found conducive to clearness to designate the lymph found in the tissue spaces as *intercellular* lymph, and that found in the lymph-vessels as *intravascular* lymph.

The Physical Properties of Lymph.—Whether obtained from tissue spaces or from lymph-vessels, the lymph presents practically the same physical properties. The lymph obtained from the thoracic duct during the intervals of digestion or from one of the large trunks of the leg is a clear, colorless or slightly opalescent fluid having an alkaline reaction and a specific gravity of 1.020 to 1.040. Examined microscopically it is seen to hold in suspension a large number of corpuscles similar to those seen in the lymph-glands and to the white corpuscles of the blood. Their number has been estimated at about 8200 per cubic millimeter, though this count will vary within wide limits according as the lymph examined has passed through a larger or smaller number of glands. The lymph-corpuscle consists of a small quantity of protoplasm in which is embedded a distinct nucleus. Some of these lymphocytes contain distinct granules, more or less refractive, which impart to the corpuscle a distinctly granular appearance. When withdrawn from the vessels lymph undergoes a spontaneous coagulation, though the coagulum is never as firm as that observed in the coagulation of the blood. The cause of the coagulation is the appearance of fibrin. After a variable length of time the coagulum separates into a liquid and a solid portion, the serum and the clot.

The Chemic Composition of Lymph.—Although the lymph obtained from the tissue spaces, from the lymph-vessels, as well as from the so-called serous cavities has the same general chemic characteristics, there is reason for the view that it varies in its ultimate composition according as it is derived from one region of the body or from another. The needs of any individual tissue as well as the character of its metabolic products will in all probability not only change its normal composition, but also the relative amounts of its normal constituents.

Chemic analysis has shown that the lymph from the thoracic duct contains from 3.4 to 4.1 per cent. of proteins (serum-albumin, fibrinogen), 0.046 to 0.13 per cent. of substances soluble in ether (probably fat), 0.1 per cent. of sugar, and from 0.8 to 0.9 per cent. of inorganic salts, of which sodium chlorid (0.55 per cent.) and sodium carbonate (0.24 per cent.) are the most abundant (Munk). There are usually in most specimens small quantities of potassium, calcium, and magnesium salts. Fibrinogen is seldom present beyond 0.1 per cent., which will account for the feeble and slow coagulation. Lymph contains both free oxygen and carbon dioxid. Of the former, however, there is but a small percentage; of the latter, about 45 vols. per cent., partially in the free state and partially combined with sodium. Urea is also present in very small amounts. This analysis indicates that lymph resembles blood-plasma in the character of its constituents, though their relative quantities vary considerably. With the exception that it contains no red corpuscles, lymph may be regarded as a diluted blood.

The Production of Lymph.—Though blood is the common reservoir of nutritive material, the latter is not available for nutritive purposes as long as it is confined within the blood-vessels. The capillary wall, thin as it is, and composed of but a single layer of endothelial cells, would be sufficient to prevent its utilization by the tissues, if it were not permeable to the liquid portion of the blood. As this is the case, however, it is found that as the blood flows through the capillary vessels a portion of the blood-plasma passes through the capillary wall and is received into the tissue spaces, where it comes into intimate contact with the tissue-cells.

The forces concerned in the passage of the constituents of the blood-plasma across the capillary wall have been the subject of much investigation. According to some investigators, diffusion, osmosis and filtration are sufficient to account for all the phenomena. For a consideration of the phenomena of diffusion, osmosis and filtration the reader is referred to paragraphs at the end of this chapter. It is assumed that the capillary wall, being an animal membrane is freely permeable to water and crystalloid bodies generally; less so, however, to colloid bodies, such as the proteids of the blood-plasma; moreover, it is further assumed that the physiologic conditions of the capillary walls are such as not only to permit of the passage of the constituents of the blood into the tissue spaces, but also the passage of the constituents of the intercellular lymph into the blood, according to laws similar at least to those determining the passage of substances through animal membranes as determined experimentally. The force giving rise to filtration is the difference of pressure between that exerted by the blood within the capillary vessels and that exerted by the fluid in the tissue spaces; hence any increase or decrease of this difference of pressure is attended by an increase or decrease in the production of lymph. Thus compression of the veins of a part which interferes with the outflow of blood from the capillaries, or a dilatation of the arterioles which increases the inflow of blood to them will increase the capillary pressure and therefore the production of lymph. The reverse conditions will, of course, diminish the intracapillary pressure and lymph production. Hemorrhages which lower the general blood-pressure may so lower the capillary pressure as not only to stop the flow of lymph to the tissues, but may give rise to a diffusion current from the tissues into the blood.

The quantitative composition of the lymph compared with that of the blood indicates that it is produced by diffusion, osmosis, and filtration. In the lymph the concentration of the inorganic salts is practically the same as in the blood; the concentration of the proteids, however, is somewhat less. These facts are in accordance with what is known regarding the diffusibility of both crystalloids and colloids through animal membranes.

According to other investigators, the production of lymph is not so much due to intracapillary pressure as it is to the specialized activities of the endothelial cells, activities which indicate that lymph is a secretion the composition of which varies in different situations by virtue of a difference in the molecular structure of the endothelial cells. As is the case with many of the secreting cells of the body, the injection of various substances into the blood apparently increases the activity of the endothelial cells, as shown by an increased lymph production without any appreciable increase of intracapillary pressure. Thus it has been shown that after the injection into the blood of sugar, sodium chlorid, sodium sulphate, urea, etc., there is an increase in the flow of lymph from the thoracic duct. The lymph, however, under these circumstances is richer in water than is normally the case. As the blood at the same time increases its percentage of water, it is assumed that the water is extracted from the tissues, by reason of an increased percentage of salts in the tissue spaces due to increased activity of the endothelial cells. A higher percentage of salts in the lymph than in the blood is difficult to account for on the diffusion-filtration theory. The injection of peptones, albumin, the extract of the muscles of the leech, crab, mussel, etc., is also followed by an increase in the amount of lymph discharged from the thoracic duct; but in this instance the lymph possesses a higher degree of concentration, being richer not only in inorganic but also in organic constituents. The cause of this increase in both the quantity and quality of the lymph is believed to be an increased activity in the secreting power of the endothelial cells. The more recent experiments of Starling indicate that in addition to the difference of pressure between the blood in the capillaries and the lymph in the tissue spaces, a new factor must be considered and that is, the permeability of the capillary wall. This he finds to vary considerably in different parts of the vascular apparatus, being greatest in the capillaries of the liver, less in the capillaries of the intestines and least in the capillaries of the extremities. It also varies doubtless in all other situations. The increase in the production of lymph by the injection of peptones, extract of muscles of the leech, the crab, etc., Starling explains by the assumption that these substances alter the properties of the capillary wall and thus increase its permeability. The difference of pressure, therefore, between blood and lymph taken in connection with the degree of permeability of the capillary wall will account for the production of lymph in all regions of the body. It is possible that all these facts may be otherwise interpreted; the subject is yet a matter of investigation.

The Functions of Intercellular Lymph.—The origin and composition of lymph, its situation and relation to the tissue cells indicate that its function is to provide the tissue cells with those nutritive materials necessary to their growth, repair, and functional activities, and to receive from the tissue cells their waste products prior to their removal by the blood- and lymph-vessels.

The necessity for the production of lymph becomes apparent when the chemic changes which the tissues undergo at all times are considered. Thus whether in a state of relative rest or in a state of activity, disintegrative changes are constantly taking place and always in direct proportion to the degree and continuance of the activity. If the tissues are to continue in the performance of their customary activities, it is essential that repair and restoration be at once established. This is made possible by the presence of lymph, and by the power which living material possesses of absorbing from the lymph the necessary nutritive materials, of assimilating them and transforming them into material like unto itself and endowing them with their own physiologic properties.

Coincidently with the loss of nutritive material, the lymph receives the waste products of the tissues and hence changes in composition. Should this change in composition continue for any length of time, the lymph would lose its restorative character and become destructive to tissue vitality. Therefore it is essential that the nutritive material be renewed as rapidly as consumed and the waste products be carried away as rapidly as produced. Both these conditions are fulfilled by the blood- and lymph-vessels.

The Absorption of Intercellular Lymph.—From the fact that lymph is being discharged from the thoracic duct into the blood, more or less continually, it is evident that lymph is being absorbed from the intercellular spaces; from which fact it may be inferred that the production of lymph is a continuous process and that it is passing through the capillaries in amounts greater than is necessary for the immediate needs of the tissues. Should this excess accumulate there would soon arise the condition of edema and an interference with the functional activities of the tissues. Therefore so soon as the accumulation attains a certain volume it is absorbed in large measure by the lymph-capillaries and transmitted to the lymph-vessels and thoracic duct. Because of the general belief that the lymph-capillaries were in open communication with the tissue spaces it was assumed that the absorption of lymph and its flow through the lymph-vessels was the result of a difference of pressure between the lymph in the tissue spaces and the blood in the innominate veins. But if the lymph-capillaries are closed vessels, as recent investigations indicate, then additional factors, in explanation of lymph absorption, must be sought for.

It is quite possible under even normal conditions of pressure in the tissue spaces that some of the more diffusible constituents of the lymph should be absorbed by the capillary blood-vessels. As to whether the relatively feebly diffusible colloids should be so resorbed is as yet a matter of investigation.

ABSORPTION OF FOODS.

The most important of the absorbing surfaces, especially in its relation to the absorption of new material, is the mucous membrane of the alimentary canal, and more particularly that portion lining the small intestine, provided as it is with specialized absorbing structures —the villi. Though certain substances can be absorbed from the mouth, it is not probable that any food is so absorbed. From the changes which the food principles undergo in the stomach it might naturally be inferred that their absorption would promptly follow. Experimental researches have demonstrated, however, that this takes place, if at all, but to a slight extent. If, however, solutions of inorganic salts, sugars, and peptones possessing a concentration of at least 5 per cent.—a degree of concentration seldom realized under normal conditions—are introduced into the stomach, their absorption will be effected, the rate of absorption following in a general way the increase, within limits, in concentration. Water is practically not absorbed from the stomach. The absorption of the products of digestion—*i. e.*, dextrose, levulose, peptones, soaps, glycerin, fatty acids, salts, along with water, in which for the most part they are held in solution—is therefore limited very largely to the small intestine, and is accomplished by the villous processes projecting from the surface of the mucous membrane.

Structure of the Villi.—The villi are small filiform or conical processes, from 0.5 to 1 mm. in length, and from 0.2 to 0.5 mm. in breadth, covering the surface of the mucous membrane from the pyloric orifice to the upper surface of the ileo-cecal valve. Each villus consists of a basement membrane (see Fig. 98) supporting tall columnar epithelial cells. Each cell is composed of granular bioplasm containing a distinct nucleus. At its free extremity a narrow border of the cell presents a striated appearance, as if it were composed of small rods embedded in some cement substance. Goblet or mucin-holding cells are also to be found among the columnar cells. The body of the villus, that portion within the basement membrane, consists of a reticulated connective tissue supporting arteries, capillaries, veins, and lymphoid corpuscles. In the center of the villus there is usually a single though at times a double club-shaped lymph-capillary, the walls of which are composed of epithelioid cells with sinuous margins. This capillary probably begins by a blind extremity and opens at the base of the villus into the subjacent lymph-vessels. The communicating orifice is guarded by a valve. It is also surrounded by a layer of non-striated muscle-fibers, arranged longitudinally, derived from the muscularis mucosæ and attached to the apex of the body of the villus.

The arteries which penetrate the villi are derived from those of the submucous coat of the intestine, which are the ultimate branches of the intestinal artery, and serve the purpose of delivering nutritive material to the capillary plexus (Fig. 99). While passing through the latter a portion of the blood-plasma transudes through the capillary walls into the spaces of the reticulated tissue, constituting lymph. At the same time products of tissue metabolism pass through the capillary walls into the blood. The blood then passes into the venules, which, leaving the villus at its base, unite with the veins of the submucous coat to form the intestinal veins. These finally unite with the gastric and splenic veins to form the portal vein, which enters the liver at the transverse fissure (Fig. 100). The excess of lymph within the villus passes into the club-shaped lymph-capillary, to be finally carried by the lymphatics of the mesentery into the thoracic duct. During the intervals of digestion and in the absence of food from the intestine there is, of course, no absorption of food nor the removal from the villus of anything but the excess of lymph and metabolic products.

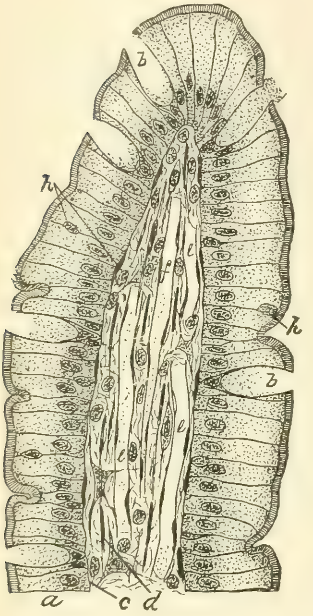


FIG. 98.—LONGITUDINAL SECTION OF A VILLUS FROM INTESTINE OF THE DOG, HIGHLY MAGNIFIED. *a*. Columnar epithelium containing goblet-cells (*b*) and migratory leukocytes (*h*). *c*. Basement membrane. *d*. Plate-like connective-tissue elements of core. *e*, *e*. Blood-vessels. *f*. Absorbent radical or lacteal.—(*Piersol.*)

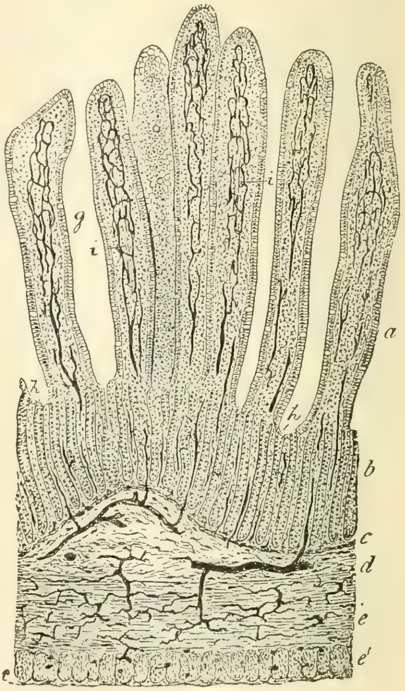


FIG. 99.—SECTION OF INJECTED SMALL INTESTINE OF CAT. *a*, *b*. Mucosa. *g*. Villi. *i*. Their absorbent vessels. *h*. Simple follicles. *c*. Muscularis mucosæ. *j*. Submucosa. *g*, *e'*. Circular and longitudinal layers of muscle. *f*. Fibrous coat. All the dark lines represent blood-vessels filled with the injection mass.—(*Piersol.*)

Function of the Villi.—The villi, and especially the epithelial cells covering them, are the essential agents in the absorption of the products of digestion. It is by the activity of these cells that the new materials are taken out of the alimentary canal and transferred into the lymph-spaces, in the body of the villi, from which they are subsequently removed by the blood-vessels and lymphatics. As to the mechanism by which the epithelial cells accomplish this result, nothing definite can be asserted. Inasmuch as the absorption of food does not take place in accordance with the laws of osmosis as at present understood, it has been suggested that the cells possess a "selective action" dependent on their organization and living condition, an action which is to a great extent conditioned and limited by the degree of diffusibility of the substances to be absorbed.

Absorption of Water and Inorganic Salts.—Water and inorganic salts after their absorption from the intestine and transference into the lymph-spaces of the villi pass through the walls of the capillary blood-vessels and are carried by the way of the portal vein into the liver. Unless water be present in excessive amounts, there is no appreciable absorption of water by the lymphatics.

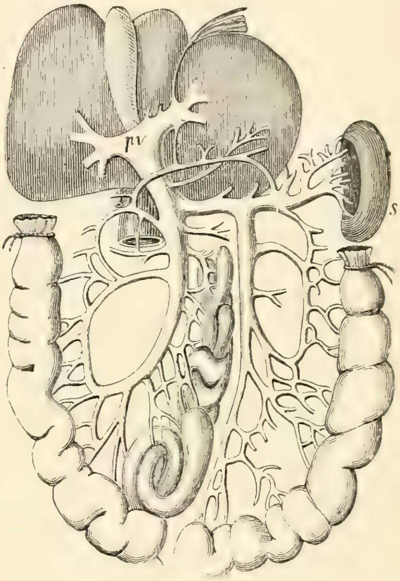


FIG. 100.—DIAGRAM OF THE PORTAL VEIN (*pv*) ARISING IN THE ALIMENTARY TRACT AND SPLEEN (*s*), AND CARRYING THE BLOOD FROM THESE ORGANS TO THE LIVER. —(*Yeo's "Text-book of Physiology."*)

Absorption of Sugar.—As previously stated, all the carbohydrates, with the exception possibly of lactose, are transformed by the digestive fluids into either dextrose or levulose, under which forms they are absorbed by the epithelial cells. It is possible, however, that soluble dextrin may also be absorbed. Whatever the form under which the carbohydrates are absorbed, they never leave the epithelial cells except as dextrose and levulose. Direct experimentation has shown that the sugars are taken up by the capillary blood-vessels and carried direct to the liver. Analysis of the blood of the portal vein after the ingestion of large quantities of sugar may reveal an increase of 0.25 per cent.; while after the injection of sugar into the intestine the percentage may rise as high as 0.4. As chemic analysis of lymph obtained from the thoracic duct shows no increase in the percentage of sugar beyond that normally present (0.1 per cent.), it is assumed that sugar is not removed from the villi by the lymphatics.

Absorption of Proteins.—Since most of the proteins are transformed through hydration and cleavage by the action of the gastric and pancreatic enzymes into peptones, there is reason to believe that this change is necessary to their complete and rapid absorption. Nevertheless it has been shown by the results of experimentation that unchanged native proteins, such as egg-albumin, and partially digested proteins, such as acid and alkali-albumin, albumoses, may likewise be absorbed from the small intestine, though in far less amounts. It has also been demonstrated that native proteins can be absorbed from the large intestine. Inasmuch as chemic analysis has failed to detect more than a trace of either peptone or native protein in the portal blood or in the lymph of the thoracic duct, it must be assumed that the epithelium after absorbing must also synthetize them into some form of coagulable protein (serum-albumin) which is readily assimilable by the blood. That such a reconversion is necessary would appear from the fact that the introduction of peptones even in small amounts into the blood is followed by their elimination unchanged in the urine. When injected into the blood in large amounts, they act as toxic agents, giving rise to a fall of blood-pressure, a diminished coagulability of the blood, coma, and death.

After passing through the epithelium into the spaces of the villi they are removed by the blood-vessels and carried direct to the liver. Even though there is no appreciable increase in the amount of protein in the portal blood during digestion, there is every reason to think that this is the route by which it reaches the general circulation. Ligation of the thoracic duct does not interfere with protein absorption nor with the normal elimination of urea nor with the weight of the animal.

The foregoing statements are based on the view that the final stage in the digestion of proteins is the formation of peptones. There are reasons however for believing that the change is more far reaching and complete, and that the peptones in turn are disintegrated and reduced to still less complex bodies represented by polypeptids, peptids and even amino-acids. The extent to which this disintegration proceeds will doubtless depend on the quantity and variety of proteins consumed.

If the reduction of the protein molecule to this fragmentary condition is the outcome of protein digestion, as recent investigations indicate, then the problem of absorption is transferred to these fragmentary bodies rather than to the peptone molecule. Inasmuch as the presence of the peptids and the amino-acids in the blood of the portal vein has not been demonstrated beyond question, the supposition is that after their absorption by the intestinal epithelium, they are synthesized and a protein molecule constructed, similar to if not identical with, the albumin of the blood-plasma. This view renders it much easier to understand how out of the different proteins, varying widely in their composition, the specific proteins of the blood are constructed. It is only necessary to assume that the epithelial cell selects from the variety of fragments presented to it, those which are necessary to the formation of the blood albumin and the blood globulin, and to synthesize them. The fate of the unused fragments is various. Some are carried to the liver and transformed into urea; others are acted on by intestinal bacteria, after which they may be eliminated in the feces or absorbed and carried to the liver where they undergo other changes and eventually appear in the urine.

Absorption of Fat.—As previously stated, there are two views as to the changes which fats undergo during digestion. According as the one or the other is accepted will depend the view as to the nature of the absorptive process. If it be assumed that the final stage in the digestion of fat is a purely physical one, the production of an emulsion in which the fats present themselves as fine granules, it is difficult to give any satisfactory explanation of the mechanism by which the epithelial cells take them up. Various theories have been advanced to explain the process, but none are free from serious objections. This view of fat absorption has largely been based on the observation that during digestion fatty granules can be seen in all portions of the cell apparently passing toward the interior of the villus. If, on the contrary, it be admitted that the final stage in the digestion of fats is the formation of soaps and glycerin, both of which are soluble, their absorption can more readily be accounted for. According to this view, the soaps and glycerin are again synthesized by a process the reverse of that which is produced by the pancreatic enzyme, with the appearance of minute granules of fat. That this is the more probable view as to the mechanism of fat absorption is evident from the fact that when animals are fed with alkaline soaps and glycerin, or with fatty acids alone, globules of fat are found in the epithelial cells and in the interior of the villus.

With the passage of the fat-granules into the interior of the villus they at once enter the lymph-radicle and become constituents of the lymph-stream, to which they impart a white, milky appearance. If the abdomen of an animal in full digestion be opened, the lymph-vessels of the mesentery present themselves as distinct white threads. An examination of the fluid they contain, known as *chyle,* shows the presence of fat-granules of microscopic size. With the passage of the chyle into the thoracic duct it also presents the same milky appearance. For this reason the lymphatics of the mesentery were erroneously termed *lacteals.* The chyle as obtained from these lymph-vessels possesses the same qualitative though not quantitative composition as lymph, the difference being mainly in the large excess of fat in the former. Indeed, chyle may be regarded as lymph plus fat.

Routes for the Absorbed Food.—Physiologic experiments have demonstrated that the agents concerned in the removal of the products of digestion after their absorption from the interior of the villus are:

1. The veins of the gastro-intestinal tract, which converge to form the portal vein.

2. The lymph-vessels of the small intestine, which converge to empty into the thoracic duct.

The products of digestion find their way into the general circulation by these two routes, as follows: (See Fig. 101).

The water, inorganic salts, proteins, and sugar after entering the blood-vessels of the villus are carried by the blood of the intestinal veins directly into the liver by the portal vein; after circulating through the capillaries of the liver and being influenced by the liver cells, they are discharged by the hepatic veins into the inferior or ascending vena cava.

The fats after entering the lymph-radicle of the villus are carried by the lymph-stream of the intestinal lymph-vessels and emptied into the receptaculum chyli from which they ascend into the thoracic duct, and by which they are discharged into the blood at the junction of the left subclavian and internal jugular veins.

Forces Aiding the Movement of Lymph and Chyle.—The force which primarily determines the movement of the lymph has its origin in the beginnings of the lymph-vessels, the lymph-spaces, and depends on a difference in pressure here and at the termination of the thoracic duct. The rise of pressure in the lymph-spaces is due to the continual production of lymph, either by filtration or secretory activity of the capillary walls. As soon as the pressure rises above that in the thoracic duct a forward movement of lymph takes place. Other things being equal, the rate of movement will be proportional to the difference of pressure. The first movement of the chyle, its passage from the lymph-capillary in the villus into the subjacent lymph-vessel, has been attributed to a shortening of the villus and a compression of the capillary by the contraction of the non-striated muscle-fibers by which it is surrounded. With the entrance of the chyle into the subjacent lymph-vessel there is a distention of the vessel and a rise in pressure. When the muscle-fibers relax, regurgitation is prevented by the closure of the valves at the base of the villus. The elastic tissue of the lymph-vessel now recoils and forces the chyle toward the thoracic duct. After the emptying of the lymph-capillary the conditions as far as pressure is concerned are favorable to the absorption of new material. The rhythmic contractions of the intestinal wall undoubtedly aid in the movement of lymph and chyle.

It is quite possible that the walls of the general lymphatic system aid the forward movement of lymph by more or less rhythmic contractions of their contained muscle-fibers.

Inasmuch as the lymph-vessels lie in situations in which they are subject to compression by muscles during contraction, it is probable that the fluid in the vessels will be forced onward toward the thoracic duct at each compression, a backward movement being prevented by the closure of the valves which are everywhere present in the vessels. Experimental observations have demonstrated the truth of this supposition. Alternate contraction and relaxation of

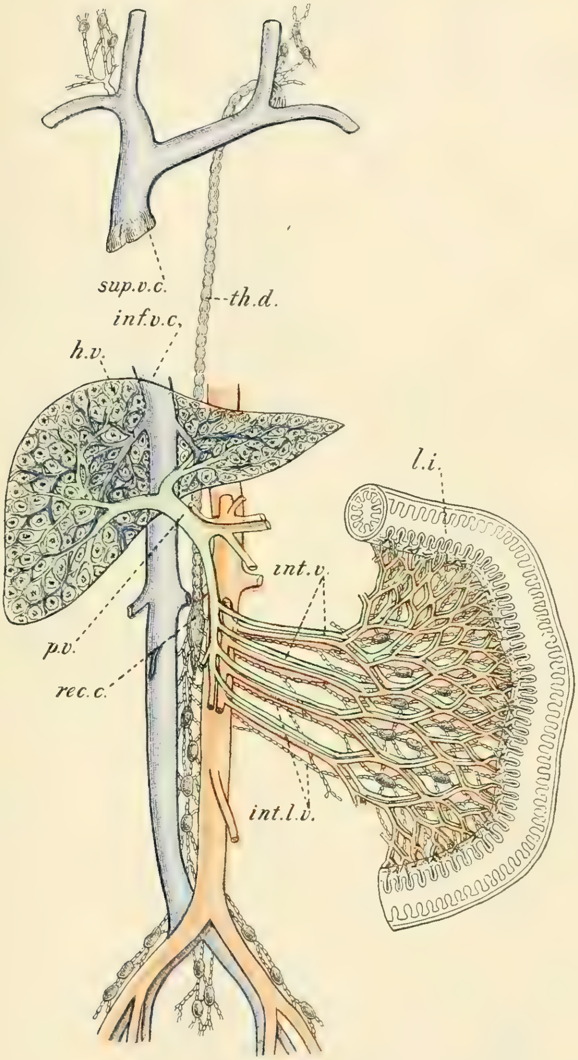


Fig. 101.—Diagram Showing the Routes by which the Absorbed Foods Reach the Blood of the General Circulation (*G. Bachman*). *l. i.*, Loop of small intestine; *int.*, *v.*, intestinal veins converging to form in part, *p. u.*, the portal vein, which enters the liver and by repeated branchings assists in the formation of the hepatic capillary plexus; *h. u.* the hepatic veins carrying blood from the liver and discharging it into, *inf. v. c.*, the inferior vena cava; *int. l. v.*, the intestinal lymph vessels converging to discharge their contents, chyle, into *rec. c.* the receptaculum chyli, the lower expanded part of the thoracic duct; *th. d.*, the thoracic duct discharging lymph and chyle into the blood at the junction of the internal jugular and subclavian veins; *sup. v. c.*, the superior vena cava.

the muscles of the leg will, in an animal at least, increase considerably the flow as well as the production of lymph from the thoracic duct. Massage has a similar influence. The respiratory movements also aid the flow of both lymph and chyle from the thoracic duct and larger lymph-vessels into the venous blood. During inspiration the negative pressure of the thorax is increased, the increase being proportional to the extent of the inspiration. The positive pressure of the air within the lungs on the thoracic structures, venæ cavæ, thoracic duct, etc., being at the same time diminished, there is an expansion of and a fall of pressure in the thoracic duct and venæ cavæ. As the lymph in the abdominal portion of the thoracic duct is subjected to the higher intra-abdominal pressure, its contents are forced energetically toward the end of the thoracic duct. During expiration the reverse conditions obtain. As the negative pressure diminishes and the positive intrapulmonary pressure increases the upper part of the thoracic duct is compressed and the lymph is forced into the subclavian vein at its junction with the internal jugular. Regurgitation here is prevented by a closure of the valves.

DIFFUSION. OSMOSIS. FILTRATION.

As these three factors are believed to play an important part in many physiologic processes, it is essential to a better understanding of these processes, that certain elementary facts relating to these three factors be known.

Diffusion.—By diffusion is meant the gradual and spontaneous mixture of the molecules of two or more liquids, or of two or more gases, when brought into contact with each other, without the application of an external force. The reason for both processes lies in the fact that the molecules of a liquid and of a gas are in constant motion, in consequence of which a mutual interpenetration of the molecules takes place, which continues until a condition of homogeneity is established.

Again, when a soluble substance, inorganic or organic, is placed in water, the molecules of the substance will at once begin to separate themselves and to diffuse throughout the water until the solution becomes homogeneous, and notwithstanding the fact that the dissolved substance possesses weight, the solution remains homogeneous. The force of gravity is overcome by the force of diffusion.

The velocity with which the molecules of a substance will diffuse through a solvent like water, varies considerably. The experiments of Graham show that if the molecules of a given weight of hydrochloric acid diffuse completely in a unit of time, the molecules of the same weight of sodium chlorid, cane-sugar, albumin and caramel, will require for their diffusion 2.33, 7, 48, and 98 units of time respectively.

Osmosis.—Osmosis may be defined as the passage of the molecules of water across an intervening membrane. If the water on one side of the membrane, parchment for example, contains in solution substances such inorganic salts, their molecules will also pass across the membrane though the time required for this to take place may be much longer than in the case of the water molecules. The passage of the dissolved substance across the membrane though usually included under the term osmosis is more properly termed dialysis.

If the two volumes of water on opposite sides of the membrane are the same in amount, and if the one volume contains a salt in solution, the salt molecules will continue to pass across the membrane until the water on both sides contains the same number of molecules, or, in other words, until it is homogeneous in composition. The time required for their passage being longer than the time required for the passage of the water molecules, there will be (owing to factors which will be explained later), a temporary increase in the volume of the water originally containing the salt, but in time the two volumes will again become equal. Certain other substances which may be in solution, such as albumin, starch, etc., will not pass across a membrane, because of the large size of their molecules. Graham termed all those substances which by virtue of the small size of their molecules pass across membranes, *crystalloids*, and all those which by virtue of the large size of their molecules do not pass across membranes or to a very slight extent, *colloids*.

It was stated in the foregoing paragraph that if two equal volumes of water are separated by a parchment septum, one of which contains in solution an inorganic salt, the molecules of the salt-free water will osmose across the septum into salt-containing water, more rapidly than they will in the opposite direction, and as a result, there will be a temporary increase in the volume of the water containing the salt. If the membrane were impermeable to the salt molecules, the difference in the two volumes of the water would be far more permanent and striking. The reason assigned for this, is that the molecules of the salt exert a pressure against the outer layer of the water molecules and these in turn against the membrane, in consequence of which there is a more rapid osmosis of the water molecules towards the salt than in the reverse direction. To this pressure is applied the term—

Osmotic Pressure.—Osmotic pressure may be defined as the pressure exerted by the molecules of the substance in solution against an enclosing wall, in consequence of which there is an osmosis of the surrounding solvent towards it. The reason for this pressure lies in the fact that, when the molecules of a substance are separated a certain distance, as they are when in solution, they repulse one another as do the molecules of a gas and in their flight strike against the outer layer of the solvent. The pressure of the molecules of a substance in solution is therefore comparable to the pressure of the molecules of a gas.

Three methods may be employed for measuring the force of the osmotic pressure of different substances, viz.: 1. Physical. 2. The determination of the freezing point. 3. By calculation.

1. *Physical Method.*—For the purpose of measuring osmotic pressure by physical methods, it is customary to make use of an apparatus similar to that represented in Fig. 102, which consists of an earthenware vessel (*a*), into the upper open end of which a tall vertical glass tube has been hermetically sealed. The pores of the earthenware vessel have been filled by a membrane made by precipitating ferro-cyanid of copper within them. This membrane is freely permeable to water, but impermeable to certain substances in solution, *e. g.*, cane-sugar. Such a membrane, which permits the passage of the molecules of the solvent but not the molecules of the dissolved substance, is termed a semipermeable membrane, and its use is absolutely necessitated when it is desired to obtain the actual pressure exerted by any given substance in solution. An apparatus of this character is termed an osmometer.

When, therefore, the osmometer containing a solution of cane-sugar is placed in the vessel (*b*) containing water, the following phenomena arise, viz.: an ascent of the cane-sugar solution in the vertical glass tube, and a descent of the level of the water in the vessel *b*. These phenomena continue until the level of the fluid in the glass tube reaches a certain height when it becomes stationary, and no further effect takes place.

In explanation of the foregoing phenomena it may be said that the molecules of the sugar strike or press against the outer layer of the molecules of the solvent, which at all points are in contact with the rigid walls of the earthenware vessel, except at the open extremity of the vertical glass tube. Inasmuch as the rigid walls of the osmometer prevent any outward displacement of the molecules of the water, the force of the impact of the sugar molecule is directed against the molecules at the extremity of the vertical tube which are in consequence pressed or pushed upward a certain distance. Because of the loss of energy due to the impact, the sugar molecule does not rebound with the same velocity, and hence time is permitted for the molecules of the water to pass into the sugar solution, to occupy the space, and thus maintain the level of the fluid in the vertical tube. (For the reason that the osmometer is permeable to water, the molecules will pass outward as well as inward though more will pass in a unit of time in the latter, than in the former direction, until equilibrium is established.) The pressure of the sugar molecules continuing, the level of the fluid in the glass tube continues to rise and the level of the fluid in the vessel, *b*, continues to fall until the force of gravity prevents any further upward movement of the molecules of sugar against the outer film of the molecules of the water. The difference in the level of the two fluids expressed in millimeters of mercury is taken as a measure of, and equal to, the pressure of the sugar in solution. A 1 per cent. solution of cane-sugar at a temperature of from 13° C. to 16° C., as determined by this method, exerts an osmotic pressure of about 535 mm. Hg.; a 2 per cent. solution exerts an osmotic pressure approximately twice this amount.

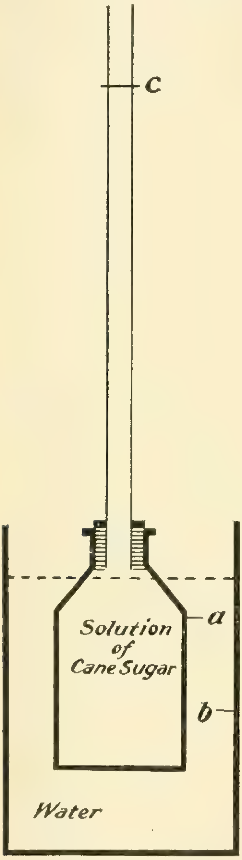


FIG. 102.—AN OSMOMETER.

Experiments made with this and similar osmometers show—

1. That the osmotic pressure of any substance in solution is proportional to the concentration, providing the temperature is constant.
2. That when the concentration is constant the osmotic pressure rises with, and is proportional to, the temperature.
3. That when different substances are present in the same solvent the osmotic pressure is equal to the sum of the individual or partial pressures.
4. That whatever the nature of the substance in solution it will exert the same osmotic pressure, providing always, the same number of molecules

are present; hence the molecular weights in grams per liter of different substances, exert the same osmotic pressure at the same temperature.

Because of the fact that when certain substances, *e. g.*, many inorganic salts, many acids and bases, are dissolved, some of their molecules undergo ionization, *i. e.*, separation into parts which are charged with electricity, and hence the two together, molecules and ions, exert a greater osmotic pressure than would otherwise be the case; and because of the further fact, that it is extremely difficult to obtain absolutely semipermeable membranes, uniform results are not obtained by the employment of the three methods; therefore, the osmometric methods as well as the calculation or arithmetic method have been largely discarded and the method based on the determination of the freezing point has been adopted.

2. *The Determination of the Freezing Point.*—Because of the difficulty in obtaining the exact osmotic pressure by means of the osmometer as stated above, reliance is now placed on the mathematic relation known to exist between osmotic pressure and the freezing point. Thus the freezing point of water holding any substance in solution is lower than water itself and is indeed proportional to the number of molecules dissolved. As a standard of comparison it is customary to employ a gram-molecule of a substance dissolved in one liter of water. (A gram-molecule is the quantity of a substance expressed in grams equal to its molecular weight.) The lowering of the freezing point of a gram-molecule solution below that of water is constant, viz., 1.87° C. The osmotic pressure therefore of such a solution, as determined by calculation (see below), is equal to 22.38 atmospheres, or 17,008 mm. of Hg.

Therefore it is only necessary to determine by means of a differential thermometer the lowering of the freezing point in degrees centigrade, which is usually expressed by the symbol $\triangle$. Then the osmotic pressure is equal to $\triangle$ divided by 1.87° C., and the quotient multiplied by 22.38 atmospheres, or 17,008 mm. of Hg. Thus if the freezing point of any solution was found to be 0.83° C. lower than water, its osmotic pressure would be $0.83 \div 1.87 \times 22.38$ atmospheres or 9.847 atmospheres = 7,483 mm. Hg. If any two solutions have the same freezing point they contain the same number of molecules and hence have the same osmotic pressure. Blood plasma has a freezing point of 0.56° C. Experimentally it has been determined that the freezing point of water is lowered to the same level, when it contains sodium chlorid to the extent of 0.95 per cent. Hence these two fluids have the same osmotic pressure and are *isotonic;* each exerts a pressure of 6.696 atmospheres.

For this reason the sodium chlorid solution can be employed for preserving, for a time at least, the form of blood corpuscles or other living mammalian cells, from which it may be inferred, that the contents of the cells have an osmotic pressure approximately equal to that of the blood plasma or the salt solution. If the salt solution has a lower concentration and hence a lower osmotic pressure, water will osmose into the corpuscle and cause a discharge of its hemoglobin content. Such a fluid is said to be *hypoisotonic.* If on the contrary, the salt solution has a higher concentration and hence a higher osmotic pressure, water will osmose from the corpuscle causing a shrinkage and crenation of the corpuscle. Such a fluid is said to be *hyperisotonic.*

3. *By Calculation.*—The osmotic pressure may also be obtained by calculation based on the known pressure exerted by a gram-molecule of hydrogen—2 grams—when compressed to a volume of one liter. It is well

known that 1 gram of hydrogen at 0° C. and at an atmospheric pressure of 760 mm. Hg. occupies a volume of 11.19 liters, and that 2 grams under the same conditions will occupy a volume of 22.38 liters, and that when the two grams, that is, the gram-molecules are compressed to a volume of 1 liter the molecules will exert a pressure equal to that of 22.38 liters or 22.38 atmospheres or 17,008 mm. of Hg. Since a gram-molecule of any substance dissolved in 1 liter of water contains the same number of molecules as a gram-molecule of hydrogen, they have the same osmotic pressure.

From this it is possible to calculate the osmotic pressure of an electrolyte, if the percentage composition of the substance in solution be known. Let it be supposed, for example, that it is desirable to know the osmotic pressure of a 1 per cent. solution of cane-sugar. The procedure is as follows: A gram-molecule of cane-sugar ($C_{12}H_{22}O_{11}$) contains 342 grams; a 1 per cent. solution contains 10 grams to the liter; hence its osmotic pressure is $10 \div 342 \times 22.38$ atmospheres or 0.65 atmosphere which is equal to 494 mm. of Hg.

Filtration.—Filtration may be defined as the passage of water and of all substances dissolved in it, across a membrane as a result of a difference of hydrostatic pressure on the two sides. The difference between the two pressures constitutes the force of filtration, and hence the greater the difference, the greater will be the amount of fluid filtered.

With any given artificially prepared animal membrane the quantities of water and crystalloids in general which pass across the membrane are proportional to the filtration force, and hence the filtrate will have a concentration similar to, if not identical with, that of the original solution. The passage of colloids in solution will be proportional to the permeability of the membrane and an increase in the filtration force. The filtrate, however, will have a lower degree of concentration than the original solution for the reason that as the pressure rises the quantity of water filtered increases in a greater ratio than the quantity of colloid filtered.

Physiologic Applications.—In the animal body the fluids are separated by delicate membranes across which the constituents of the fluids, inorganic and organic, are continually passing. Thus prepared foods in the intestine pass across the intestinal wall into blood- and lymph-vessels; the constituents of the blood pass across the wall of the capillary vessel into the tissue spaces from which they pass (*a*) through the walls of various glands to take part in the formation of their secretion; (*b*) across the sarcolemma into the interior of the muscle fiber; (*c*) across the limiting surface of, and into the interior of all tissue cells. The waste products, the result of tissue and food metabolism, pass from the interior of cells across their limiting membranes or surfaces into the tissue spaces; thence across the wall of the capillary vessel into the blood and finally across the wall of the capillary vessel and the epithelium of the lung, the kidney, the liver, etc., to take part in the formation of the excretions. These and other processes are believed to be accomplished by the factors, diffusion, osmosis and filtration.

The statements that have been made in foregoing paragraphs in reference to diffusion, osmosis and filtration have been based on the results of experiments which have been made with non-living membranes, and under conditions purely physical; and though it is quite true that in the animal body the fluids are separated by membranes more or less permeable to all their constituents, and that all pass across these membranes, it is possible that the facts which have been obtained experimentally are not strictly paralleled in the living body, and hence not strictly applicable to the elucidation of physiologic processes. Nevertheless there are reasons for thinking that a thorough understanding of these factors will eventually throw much light on the intimate nature of the process by which organic as well as inorganic substances in solution pass across animal membranes in the living condition.

CHAPTER XII.

THE BLOOD.

The blood is a highly complex nutritive fluid, the presence and proper circulation of which in the living organism are essential to the maintenance and activity of all physiologic processes. The escape of the blood from the vessels, especially in the higher animals, is followed by a loss of the physiologic properties of all the tissues within a short period of time. The immediate dependence of the functional activities of the tissues and organs on the presence of the blood can be demonstrated by the following experiment: If the nozzle of a syringe, adapted to the size of the animal, be introduced through the jugular vein into the right side of the heart and the blood be suddenly withdrawn, there is an immediate cessation in the activity of all the organs; the return of the blood to the vessels within a limited period of time is promptly followed by a renewal of their activity.

Though contained within a practically closed system of vessels, the blood is brought into intimate relation with all the tissue elements through the intermediation of the capillaries. As the blood flows through these delicate vessels, portions of its soluble nutritive constituents, including oxygen, are given up to the tissues, by which they are utilized for growth, repair, and functional activity. At the same time the tissues yield up to the blood a series of decomposition products, resulting from their activity, which vary in quantity and quality according as the blood traverses the muscles, nerves, glands, or other tissues.

The blood may be regarded, therefore, as a reservoir of nutritive materials prepared by the digestive apparatus and absorbed from the food canal; of oxygen, absorbed from the respiratory surface of the lungs; of decomposition products, produced by and absorbed from the tissues. Though the blood varies in composition in different parts of the body in consequence of the introduction of both nutritive material and decomposition products, it nevertheless presents certain average physical, morphologic, and chemic properties which distinguish it as an individual tissue.

Constituents of Blood.—A microscopic examination of the blood as it flows through the capillary vessels of the web of the frog or the mesentery of the rabbit shows that it is not a homogeneous fluid, but that it consists of two distinct portions: viz., (1) a clear, transparent, slightly yellow fluid, the plasma or liquor sanguinis; (2) small particles termed corpuscles floating in it, of which there are two varieties, the red or the erythrocytes and the white or the leukocytes. By appropriate methods it can be shown that a third corpuscle, colorless in appearance and smaller in size than the ordinary white corpuscle, is present in the blood-stream and known as the blood-plate or plaque. The different constituents can be roughly separated by appropriate means when the blood is withdrawn from the body. If the blood of the horse is allowed to flow directly into a tall cylindric glass vessel, surrounded by ice, it separates in the course of a few hours into three distinct layers in accordance with their specific gravities. The lower layer is dark red and consists of the red corpuscles; the middle layer is grayish in color and consists of the white corpuscles; the upper layer is clear and transparent and consists of the plasma. The red corpuscles occupy almost one-half, the white one-fortieth, the plasma a trifle more than one-half of the height of the entire blood-column, which indicates approximately the different volumes of each. The same result can be obtained with human blood by the use of the centrifuge or hematocrit.

PHYSICAL PROPERTIES OF BLOOD.

1. **Color.**—Within the blood-vessels two kinds of blood are distinguished—the arterial, the color of which is a bright scarlet, and the venous, the color of which is a dark bluish-red or purple. The cause of the color as well as the difference in color is the presence in the red corpuscles of a coloring-matter, hemoglobin, in different degrees of combination with oxygen. The intensity of the color in either kind of blood is dependent on the thickness of the blood-stream, for in the finest capillaries, as seen under the microscope, there is an almost total absence of color. As the arterial blood passes into and through the systemic capillaries, the hemoglobin yields up a portion of its oxygen to the tissues and changes in color, though the change is not appreciable by the eye. On passing into the veins, however, the blood-stream soon presents its characteristic dark bluish color, which deepens as it approaches the lungs. On passing into and through the capillary vessels of the lungs the hemoglobin absorbs a new volume of oxygen, changes in color, and on emerging from the lungs the blood presents its characteristic scarlet color.

2. **Opacity.**—Owing to the fact that the corpuscles have a refracting power different from the plasma, the blood, even in thin layers, is opaque. The repeated refractions and reflections which light undergoes in passing through plasma and corpuscles is attended by such a dissipation that it is impossible to see printed matter through it. That the opacity is due to the shape of the corpuscles rather than to their contained coloring-matter is evident from the fact that when the hemoglobin is caused to separate from the corpuscles by the addition of chemic reagents, the blood, though it deepens in color, becomes at once transparent.

3. **Odor.**—When freshly drawn the blood possesses a peculiar

characteristic odor which has been attributed to the presence of a volatile fatty acid in combination with an alkaline base. The intensity of the odor may be increased by the addition of concentrated sulphuric acid, by means of which the volatile acid is set free.

4. **Specific Gravity.**—The specific gravity of blood lies within the limits of 1.051 and 1.059, averaging in man 1.056 and in woman 1.053. Normally, variations from these values are only temporary and are connected with variations in physiologic processes. The specific gravity is diminished by the ingestion of liquids and abstinence from solid food. It is increased by abstinence from liquids, by the ingestion of dry food, and by the elimination of large quantities of water by the lungs, skin, and kidneys.

5. **Alkalinity.**—The reaction of the blood is alkaline from the presence of the disodium phosphate (Na_2HPO_4) and the sodium carbonate, Na_2CO_3. The alkalinity can be readily shown by allowing the blood to remain for a few seconds on slightly reddened glazed litmus paper. On washing off the blood a distinct blue color presents itself against a red or violet background. The alkalinity varies within narrow limits in consequence of variations in physiologic processes. It is increased in the early stages of digestion and decreased in the later stages. It is decreased after muscular exercise in consequence of the increased production and absorption of acids. According to v. Jaksch, the alkalinity corresponds to from 260 to 300 milligrams of sodium hydrate, NaOH, for every 100 c.c. of blood; according to Löwy, from 300 to 325 milligrams. The hitherto unavoidable error in these estimates is about 30 milligrams.

6. **Temperature.**—The temperature varies from 36.78° C. (98.2° F.) in the superior vena cava to 39.7° C. (103.4° F.) in the hepatic vein, the mean being about 38° C. (100° F.).

Coagulation of the Blood.—Within a few minutes after the blood is withdrawn from the vessels of a living animal it begins to lose its fluidity, becomes somewhat viscid, and if left undisturbed passes rapidly into a semisolid or jelly-like state. To this change in the physical condition of the blood the term coagulation has been applied. The blood, during the progress of coagulation, not only assumes the shape of the vessel in which it is contained, but becomes so firmly adherent to its walls that it may be inverted without the coagulum becoming dislodged. If a portion of such a jelly-like mass be examined microscopically, it will be found to be penetrated in all directions by a felt-work of extremely fine delicate fibrils, which, having made their appearance before the corpuscles had time to settle to the bottom of the fluid, have entangled them in the meshes so that the entire mass retains its characteristic color. These fibrils are collectively known as fibrin (Fig. 103).

If the coagulated blood be allowed to remain undisturbed, a clear, transparent, slightly yellowish fluid makes its appearance on the surface of the mass, which as it accumulates forms a layer of varying degrees of thickness. Within a few hours the blood-mass detaches itself from the sides of the vessel in consequence of the retraction of the fibrils, while at the same time the clear fluid increases in amount and accumulates along the sides and bottom of the vessel. The shrinkage in the volume of the red coagulum and the increase of the volume of the clear fluid which is expressed from its meshes continue for a period varying from ten to fifteen hours, according to certain external conditions. The blood has now become separated into two distinct portions: viz., a solid contracted red mass, termed *clot*, and a clear fluid, termed *serum*. The clot consists of the fibrin containing in its meshes the red and white corpuscles; the serum consists of all the constituents of the plasma except the antecedents of the fibrin. The stages of coagulation are shown in Fig. 103.

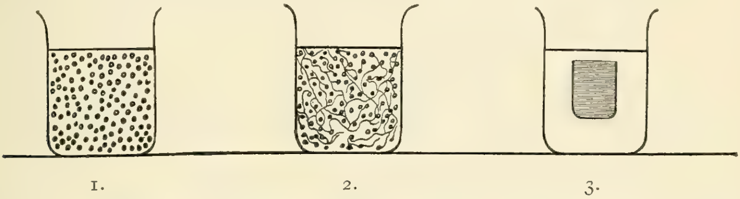


FIG. 103.—DIAGRAM TO ILLUSTRATE THE PROCESS OF COAGULATION. 1. Fresh blood, plasma, and corpuscles. 2. Coagulating blood (birth of fibrin). 3. Coagulated blood (clot and serum).—(*Waller.*)

If the blood coagulates slowly the red corpuscles, owing to their greater specific gravity, subside to the bottom of the blood-mass, giving to it a deeper color; the white corpuscles, owing to their lesser specific gravity, remain near the surface of the clot and give to it a more or less whitish appearance, producing the so-called *buffy coat.* In certain inflammatory conditions the coagulating power of the blood is much diminished, and the corpuscles, having time to subside, a well-developed buffy coat is formed which at one time had much interest for pathologists. As the contraction of the fibrin takes place more actively in the center, there being here less resistance than at the sides of the coagulum, the upper surface usually becomes depressed or cupped.

Coagulation of Plasma.—Clear plasma may be obtained by means of the centrifuge from blood to which sufficient magnesium sulphate has been added to prevent coagulation, or from horse's blood which has been allowed to flow into a tall vessel surrounded by a cooling mixture so as to prevent coagulation and thus permit the red corpuscles to subside. If such plasma be subjected to room-temperature, it very shortly undergoes coagulation, exhibiting practically the same phenomena as blood itself. After a variable length of time it also separates into a soft, colorless coagulum or clot consisting of fibrin, and a clear fluid, the serum. The presence of the red corpuscles is therefore not essential to the process of coagulation.

Rapidity of Coagulation.—The rapidity with which the blood coagulates varies in different classes of animals under the same conditions: *e. g.*, the blood of the pigeon coagulates immediately; that of the dog, in from one to three minutes; that of the horse, in from five to thirteen minutes; that of man, in from four to seven minutes. The time, however, can be lengthened or shortened by either changing the external conditions or by altering temporarily the normal composition of the blood.

Coagulation is retarded or prevented by the following agents, viz.: (1) A low temperature, especially that of melting ice. (2) The addition of magnesium sulphate (1 volume of a 25 per cent. solution to 3 volumes of blood); of sodium sulphate (1 volume of a saturated solution to 7 volumes of blood). (3) The addition of potassium oxalate (1 volume of a 1 per cent. solution to 3 volumes of blood). (4) The injection into the blood of commercial peptone. (5) The mouth secretion of the leech.

Coagulation is hastened by the following agents, viz.: (1) gradually increasing temperature from 38° C. to 50° C. (2) The addition of water in not too large amounts. (3) The presence of foreign bodies. (4) Agitation of the blood—*e. g.*, stirring.

Fibrin and Defibrinated Blood.—If freshly drawn blood is stirred with a bundle of twigs or glass rods for a few minutes, the fibrin collects on them in the form of thick bundles or strands; after washing it with water the entangled corpuscles are removed, when the fibrin assumes its natural white appearance. The strands can be resolved into a large number of delicate fibers which possess extensibility and retractibility, and are therefore elastic. The chemic features of fibrin have already been considered (see page 20). The remaining fluid, similar in its physical appearance to the blood, is termed *defibrinated blood.* When such blood is allowed to remain at rest for a few days, the remaining red corpuscles gradually sink to the bottom of the fluid, above which will be found the clear serum.

COMPOSITION OF PLASMA AND SERUM.

Plasma.—The plasma obtained by any of the methods previously described is a clear, colorless, transparent, slightly viscid fluid, with a specific gravity of 1.026 to 1.029. It is composed largely of water holding in solution proteids, sugar, fatty matter, inorganic salts, urea, cholesterin, lecithin, etc. In composition it is quite complex, containing as it does not only the nutritive materials derived from the digestion of the food, but also the substances resulting from the disintegration of the tissues consequent on their functional activity.

Serum.—The serum is the clear, transparent, slightly yellow fluid expressed from the coagulated blood during the contraction of the fibrin. It consists practically of the ingredients of the plasma, with the exception of those substances which entered into the formation of fibrin. The average composition of plasma is shown in the following table:

COMPOSITION OF PLASMA.

Water,		90.00
Proteids	Serum-albumin,	4.50
	Paraglobulin,	3.40
	Fibrinogen,	0.30
Fatty matters,		0.25
Sugar,		0.10
Extractives,		0.60
Inorganic salts,		0.85
		100.00

Serum-albumin.—Of the proteid constituents of the blood, serum-albumin is the most abundant, existing to the extent of from 4 to 5 per cent. From its similarity to egg-albumin it is regarded as holding an important position as a nutritive agent, for it is out of this common proteid that in all probability each individual tissue elaborates the special proteid characteristic of it, since during starvation the albumin steadily diminishes in amount. As it passes through the walls of the capillary vessels it is found in the lymph, pericardial fluid, and similar secretions in various parts of the body, as well as in various pathologic transudates. It is also present in serum. While circulating in the lymph-spaces the serum-albumin is utilized in replacing the proteids which have undergone disintegration during tissue metabolism. Its supply in the blood is maintained by the absorption of peptones which are formed from the proteids of the food and which during the time of absorption are changed in some unknown way into serum-albumin. It is readily obtained from plasma or serum by saturating either of these fluids with magnesium sulphate, when all the proteids except serum-albumin are precipitated. After their removal the remaining fluid is subjected to a temperature of from 70° to 75° C., when the serum-albumin is precipitated in a coagulable form, after which it can be removed and its chemic features determined.

Paraglobulin.—This proteid, though present in plasma, is best obtained from serum when this fluid is saturated with magnesium sulphate. As the line of saturation is approached the fluid becomes turbid, and after a few minutes a fine white precipitate occurs. It can then be collected on a filter, dried, and its chemic properties determined. In its reactions it resembles the various members of the globulin class. The amount varies from 2 to 4 per cent. in the blood of man. As to the physiologic importance or antecedents of paraglobulin nothing is definitely known. Its constant presence in the blood would indicate that it plays an equally important, though perhaps different, part with serum-albumin in the nutrition of the body.

Fibrinogen.—This proteid can be obtained from plasma, lymph, pericardial, and peritoneal fluids, as well as from hydrocele fluid.

It is, however, not to be obtained from serum, as it is removed from the blood during the formation of solid fibrin. It is normally present in the blood in very small quantity, amounting to not more than 2.2 to 3.3 parts per thousand. Fibrinogen may be obtained from plasma which has been prevented from coagulating, by the addition of magnesium sulphate in certain quantities or by the addition of a saturated solution of sodium chlorid. In a few minutes a flaky precipitate occurs. By repeated washing and precipitation with sodium-chlorid solutions of varying strength the fibrinogen may be obtained in a pure state. The history of fibrinogen is unknown. Beyond the fact that it contributes to the formation of fibrin there is no positive knowledge either as to its origin, its nutritive value, or its final disposition in the blood under normal conditions.

Fat.—The plasma as well as the serum contains a very small quantity of fat in the form of microscopic globules. Though the percentage is normally not above 0.25, yet just after a meal rich in fatty matter the amount may be so great as to give to the blood a milky or opalescent appearance. Within a few hours, however, this excess of fat disappears from the blood, though its immediate disposition is unknown. Soaps or alkaline salts of the fatty acids, though formed during the digestion of fats, are not present in the blood. Lecithin and cholesterin are present in very small quantities.

Sugar.—Sugar is present in the blood in the form of dextrose, and is now regarded as a normal constituent. The amount is about 1 part per thousand, though it may be present to the extent of 3 parts per thousand. Beyond this, the excess soon appears in the urine.

Extractives.—The blood contains a series of nitrogenized bodies, such as urea, uric acid, creatin, creatinin, xanthin, etc., which result from the katabolic changes in nerve- and muscle-tissues as well as from subsequent chemic combinations and decompositions. Though constantly absorbed from the tissues, they seldom accumulate beyond a small amount, since they are constantly being eliminated from the blood by the various excretory organs.

Inorganic Salts.—The inorganic salts of the plasma are chiefly sodium and potassium chlorids, sulphates, and phosphates, together with calcium and magnesium phosphates. Of the salts, sodium chlorid is the most abundant, amounting to 5.5 parts per thousand. Some of the salts are alkaline and impart to the blood its alkalinity. Calcium phosphate is present in small quantity—2 parts per 1000. This salt is wanting in serum for the reason that it became a constituent of fibrin at the time of coagulation. In other respects serum differs but slightly from plasma in the proportions of its saline constituents.

HISTOLOGY OF THE RED CORPUSCLES OR ERYTHROCYTES.

The histologic features of the red corpuscles are readily observed in a drop of freshly drawn blood when examined microscopically.

The field of the microscope will be seen to be crowded with red corpuscles floating in a clear transparent fluid—the plasma. Here and there will also be seen a white corpuscle, round or irregular in shape, and granular in appearance. Within a short time a characteristic phenomenon takes place: viz., the arranging of the corpuscles in the form of columns of varying lengths, resembling rolls of coins. These rolls interlace with each other at all angles and form a network in the meshes of which lie individual red and white corpuscles. (See (Fig. 104.) The cause of this tendency of the corpuscles to adhere to one another is not definitely known. Since it does not take place in circulating blood, and since it is to a great extent prevented by defibrinating the blood, it has been supposed to be dependent on the formation of some adhesive substance connected with the formation of fibrin.

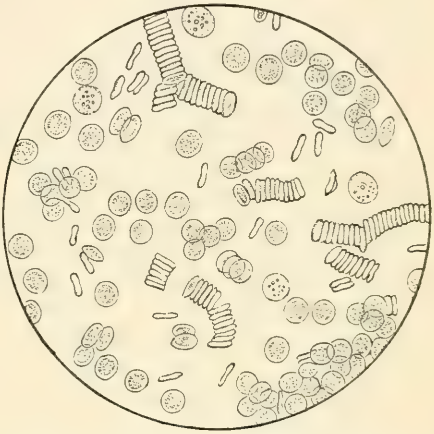


FIG. 104.—CORPUSCLES FROM HUMAN SUBJECT. A few colorless corpuscles are seen among the colored discs, many of which are arranged in rouleaux.—(*Funke.*)

Color.—When viewed by transmitted light, a single corpuscle is slightly yellow or greenish in color; but when a number are grouped together, the color deepens and the corpuscles appear red. In either case the color is due to the presence in the corpuscle of a specific coloring-matter, hemoglobin.

Shape.—The red corpuscle is a circular, flattened disk with rounded edges. Each surface is perfectly smooth and presents a shallow depression in its center, so that it is also biconcave. A longitudinal section of a corpuscle would present, when viewed edgewise, an outline similar to that of Fig. 105. This difference in the thickness of the peripheral and central portions of the corpuscle gives rise to differences in optical appearances when examined microscopically. At a certain distance of the object-glass the corpuscle presents in its peripheral portion a bright rim, and in its central portion a dark spot. If the objective be brought nearer and the center accurately focused, the reverse appearance obtains; the central portion becomes bright and the peripheral portion dark. The cause of this difference in optical appearance is the unequal

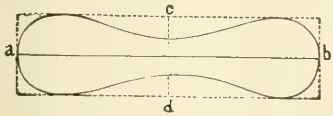


FIG. 105.—IDEAL TRANSVERSE SECTION OF A HUMAN RED CORPUSCLE. (Magnified 5000 times.) *a, b.* Diameter. *c, d.* Thickness.

distribution of the transmitted light in consequence of the shape of the corpuscle.

Size.—The diameter of a typical well-developed red corpuscle under normal conditions is 0.0075 mm., its greatest thickness is 0.0019 mm. Though this may be assumed as the average diameter, there is a small percentage of distinctly smaller and a small percentage of distinctly larger corpuscles. The following table shows the results of measurement made by different observers:

		Normal Limits.	Average Diameter.
Welcker,	diameter	0.0045–0.0095 mm.	0.0070 mm.
Hayem,	"	0.0060–0.0088 "	0.0075 "
Gram,	"	0.0067–0.0093 "	0.0078 "
Melassez,	"		0.0076 "
			0.00747 ($\frac{1}{3200}$ inch)

Structure.—The red corpuscle of man as well as of all other mammals possesses neither a nucleus nor a limiting membrane, but appears to consist of a homogeneous substance more or less semisolid in consistence. Under the influence of certain reagents the corpuscle separates into two distinct portions: viz., a colorless protoplasmic stroma and a coloring-matter which diffuses into the surrounding liquid. The presence of the former can be demonstrated by the addition of iodin, which imparts to it a faint yellow color. The stroma is elastic, and determines not only the shape of the corpuscle but gives to it the properties of extensibility and retractibility.

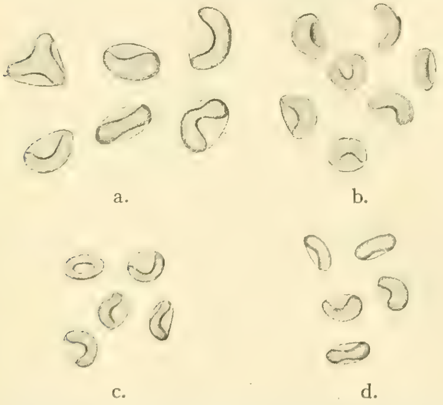


Fig. 106.—The Shape of the Red Corpuscle in Different Mammals. (*Weidenreich.*) a. Man. b. Dog. c. Pig. d. Rabbit.

The foregoing is the classic and generally accepted view as to the shape, size, and structure of the red corpuscle. Nevertheless recent investigations render it probable that the statements were based on observations of the corpuscles under artificial rather than natural conditions, and therefore not strictly true. For many years histologists from time to time have stated that the red corpuscle is not circular and biconcave in shape, in the circulating blood, but bell shaped, similar to that shown in Fig. 106. It was not until 1902, after the publication of Weidenreich's investigations that this view began to receive more attention than had hitherto been accorded it. Weidenreich preserved in a moist chamber a hanging drop of human blood, and on examination found that the red corpuscles were bell shaped though the depth of the bell cavity varied considerably. An examination of the capillary circulation in the omentum of the rabbit revealed the fact that the corpuscles in their natural medium were also bell shaped. The circular biconcave shape they ordinarily present when a drop of blood is examined microscopically he attributes to cooling, evaporation and concentration of the drawn blood. Experimentally it was shown that when blood was added to 0.6 to 0.65 per cent. solution of sodium chlorid all the corpuscles were bell shaped; but if the solution was increased or decreased in strength, this form was at once changed.

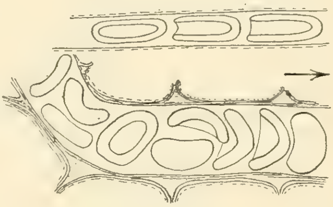


FIG. 107.—RED CORPUSCLES SKETCHED WHILE CIRCULATING IN THE VESSELS OF THE OMENTUM OF A GUINEA-PIG. (*F. T. Lewis in Stöhr's Histology.*)

The dimensions of the bell-shaped cell according to Weidenreich are as follows:—

Greatest diameter	7	microns	0.007	mm.
Diameter of cavity	3	"	0.003	"
Height of cell	4	"	0.004	"
" " cavity	2.5	"	0.0025	"
Thickness of wall at apex	2	"	0.002	"
" " " " base	1.5	"	0.0015	"

The foregoing observations have been confirmed by many subsequent investigators. Thus Lewis states that if a drop of blood is placed immediately on a warm slide and examined, the corpuscles exhibit the bell shape, but as the slide cools they gradually become biconcave disks of the conventional form. He also observed that the corpuscles in the capillary blood-vessels of the omentum of the guinea-pig were bell shaped and presenting an appearance similar to that shown in Fig. 107. Radasch found on examination of fetal tissues such as the spleen, kidney, liver, placenta, etc., that the great majority of the corpuscles in all situations presented the bell shape rather than the circular biconcave shape. This observer is of the opinion that the bell shape can not be due to the action of the fixatives employed in the preparation of the tissues.

The structure of the corpuscle, according to Weidenreich, differs also from that usually stated. He asserts that the corpuscle is surrounded by a structureless, colorless membrane enclosing a colored but not nucleated semi-fluid mass, which consists chemically of protein material, inorganic salts and hemoglobin. There is no evidence of the existence of a stroma in the adult state.

Number of Red Corpuscles.—In any given specimen of blood the corpuscles are so numerous and the spaces between them so small that it seems almost impossible to determine their number. This, however, has been accomplished for a cubic millimeter of blood by various observers employing different methods with comparatively uniform results. The average normal number of corpuscles in one cubic millimeter of blood is, for men, 5,000,000; and for women, 4,500,000. This value, however, will vary within slight limits, with variations in the activity of physiologic processes and to a large extent at times in pathologic states of the blood or body. The number is increased in the cutaneous veins by all influences which cause a diminution in the quantity of water in the blood—*e. g.*, copious sweating, acute watery diarrhea, fasting, abstinence from liquids; the number is diminished by influences which dilute the blood—*e. g.*, the ingestion of liquids, the absorption of fluids from the tissue spaces, etc. But it is well to remember that these influences which produce changes in the number of corpuscles per cubic millimeter do not necessarily produce corresponding changes in the total number of red corpuscles in the body. In women lactation, menstruation, and the act of parturition diminish the number. High altitudes apparently increase the number of corpuscles, as shown by their increase in the blood of the peripheral vessels. Whether this is an indication that there is a corresponding increase of the total number in the general volume of the blood is uncertain. The following table will show the increase in the count per cubic millimeter at different altitudes:

PLACE.	HEIGHT ABOVE SEA-LEVEL.	RED CELLS.	AUTHOR.
Christiania, ...	0 meter	4,974,000	Laache.
Göttingen, ...	148 meters	5,225,000	Schaper.
Tübingen, ...	314 "	5,322,000	Reinert.
Zürich, ...	414 "	5,752,000	Steirlin.
Auerbach, ...	425 "	5,748,000	Köppe.
Reibaldsgrün, ...	700 "	5,900,000	"
Arosa, ...	1800 "	7,000,000	Egger.
The Cordilleras, ... Moro cocha.	4392 "	8,000,000	Viault. (Köppe.)

This increase in the number of corpuscles takes place, according to Viault's observations, within two or three weeks, and is apparently not connected with either diet or mode of life, but rather with diminished atmospheric, if not oxygen, pressure. On returning to sea-level there is a gradual reduction, without any apparent destruction of the corpuscles, to their normal number. The reason for these variations is not clear.

The method of counting corpuscles introduced by Vierordt and Welcker has been modified by different observers, and especially by Thoma. On account of the great number of corpuscles in 1 cubic millimeter of blood, it becomes necessary for purposes of enumeration that the blood be diluted a definite number of times and that the diluted mixture be placed in a counting chamber possessing a definite capacity. By means of the pipette or *mélangeur* of Potain and the counting chamber of Thoma both these objects are attained.

The pipette consists of a capillary tube (Fig. 108) provided with an enlargement containing a freely movable small glass ball, a. One end of the tube is pointed, while to the other end is attached a rubber tube for the purpose of facilitating the introduction of the blood and the diluting fluid. The capillary tube, which is accurately calibrated, carries marks, ½, 1, 101, which signify that if the tube be filled with blood up to the mark 1 and the diluting fluid be sucked into the tube up to the mark 101, the blood will be diluted 100 times. If the blood be sucked up to the mark ½ and the diluting fluid to 101, then the blood will be diluted 200 times. In using the pipette the point is introduced into a drop of blood derived from a small wound in the skin of the lobe of the ear or finger and sucked into the tube by introducing the rubber tube into the mouth. The tube is then quickly inserted into a solution, which will preserve the shape and size of the corpuscles, such as Gowers's sodium sulphate solution, sp. gr. 1.025, or a 3 per cent. sodium chlorid solution,* and the fluid sucked into the tube up to the mark 101. On shaking the pipette for a few minutes, the admixture will take place, aided by the movements of the glass ball.

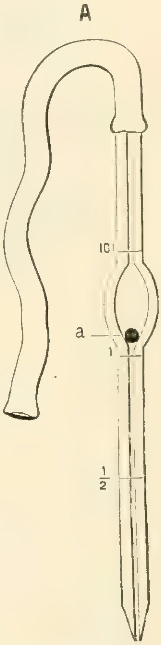


FIG. 108.—MELANGEUR OR PIPETTE.—(*Landois and Stirling.*)

Fig. 109 shows both a section view, A, and a surface view, C, of the counting chamber. This consists of an oblong glass plate on which are cemented two small pieces of glass, one of which has in the center a circular opening in which is placed the other, a circular disc or stage. Their relation is such that a narrow groove or moat separates the one from the other, the floor of which is formed by the glass plate. The surface of the circular stage is exactly 0.1 mm. lower than that of the cover-glass, a. On the surface of the glass stage a series of small squares is engraved, each one of which has a side length of $\frac{1}{20}$ mm. and an area of $\frac{1}{400}$ square mm., B. To facilitate counting, a group of 16 squares is surrounded by a heavy dark line. This group is separated from adjoining groups, also enclosed by dark lines, by an intermediate light line,

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*Various solutions have been devised for diluting blood, any one of which may be employed, *e. g.:*

Hayem's Fluid:

Hydrarg. bichlor.,	0.5 gm.
Sodium sulphate,	5.0 "
Sodium chlorid,	2.0 "
Aquæ destillat.,	200.0 "

Toisson's Fluid:

Aquæ destillat.,	160.00 parts.
Glycerinæ,	30.00 "
Sodium sulphate,	8.00 "
Sodium chlorid,	1.00 "
Methyl-violet,	0.025 part.

Gowers's Fluid:

Sodium sulphate,	gr. 104
Acid. acetic.,	ʒj
Aquæ dest.,	q. s. ad ℥iv.

which serves as a guide in passing from one group to another. When a cover-glass is accurately applied to the glass, b, each one of the small squares will have a cubic capacity of $\frac{1}{400} \times 0.1$, or $\frac{1}{4000}$ cubic millimeter, and every four such squares will have therefore a capacity of $\frac{1}{1000}$ cubic millimeter.

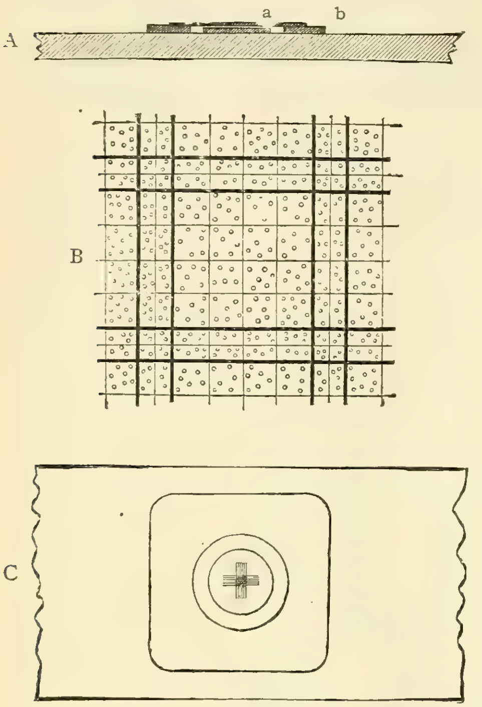

FIG. 109.—APPARATUS OF THOMA AND ZEISS FOR COUNTING THE CORPUSCLES. A. IN section. C. Surface view without cover-glass. B. Microscopic appearance with the blood-corpuscles.—(*Landois and Stirling.*)

Before placing the diluted blood on the counting stage, the fluid in the tube of the pipette should be blown out and discarded, as it contains no portion of the blood. A small drop is then placed on the glass stage and covered with the cover-glass. After a few minutes the corpuscles settle over the ruled spaces and are ready for counting. The number of corpuscles in at least five series of sixteen small squares is then counted; this number is then multiplied by the degree of dilution (100 or 200 as the case may be) and this by the cubic contents of each small square (4000); the product is then divided by the number of squares counted (80 in the instance given above): *e. g.*, five series of sixteen small squares contain 500 corpuscles

$$\frac{500 \times 200 \times 4000}{80} = 5{,}000{,}000 \text{ erythrocytes per c.mm.,}$$

or,

$$500 \times 10{,}000 = 5{,}000{,}000, \text{ erythrocytes per c.mm.}$$

The accuracy of the counting is proportional to the number of squares counted. If 200 squares are counted with each of two different drops, and the average taken the probable limit of error will be less than 2 per cent.

The Effects of Reagents on the Red Corpuscles.—Within the blood-vessels the physical conditions and chemic composition of the plasma are such that both the form and the composition of the corpuscle or the relation of the hemoglobin to the stroma, are maintained in the normal or physiologic condition. The plasma is preservative of the structure and function of the corpuscle. The reason assigned for this is that the osmotic pressure of the salts in the plasma and of the salts in the corpuscle exactly balance one another so that there is neither an absorption of water from, nor a yielding of water to, the plasma on the part of the corpuscle. The plasma having an osmotic pressure equal to that within the corpuscle is said to be *isotonic* with it.

When blood is to be prepared for microscopic examination with a view of determining the histologic features of the corpuscles or for purposes of enumeration, it must be diluted, and unless special precautions are observed the condition of equal osmotic pressure will be disturbed by the diluting agent and the corpuscles will lose their characteristic form and structure from either an absorption or loss of water, as the case may be.

If distilled water is employed for this purpose, the osmotic pressure of the plasma is of course diminished, and in consequence the osmotic pressure of the constituents of the corpuscles (particularly sodium chlorid) causes an inflow of water. The corpuscle therefore swells and assumes a more or less spheric form; the hemoglobin is dissociated and discharged into the surrounding fluid throughout which it diffuses. Such an environment having an osmotic pressure less than that of the corpuscle is said to be *hypotonic*, *hypisotonic*, or *hypoisotonic* to it.

If on the contrary, water containing inorganic salts (particularly sodium chlorid) in amounts which impart to the plasma an osmotic pressure greater than that within the corpuscle, there will be an outflow of water from the corpuscle, a shrinkage of the volume and a crenation of its surface. Such an environment having an osmotic pressure greater than that of the corpuscle is said to be *hypertonic*, or *hyperisotonic* to it. It becomes essential therefore in diluting the plasma with water, that the latter contains inorganic salts in such amounts that the resulting mixture (plasma and water) possesses an osmotic pressure equal to that of the original plasma or to that of the corpuscle. A diluting agent well adapted for this purpose is the well-known Ringer's mixture. Other solutions which preserve the form of the corpuscles during the time required for their enumeration are the solutions devised by Hayem, Toisson and Gower alluded to on a preceding page. Because of the fact that sodium chlorid is the chief inorganic constituent of the plasma and of the corpuscle it is common in laboratory work to dilute the plasma of mammalian blood and of frog's blood with solutions of sodium chlorid of 0.9 per cent. and 0.6 per cent. respectively, which though not absolutely are sufficiently isotonic for the purpose desired.

Many other saline solutions with an osmotic pressure greater or less than normal plasma, dilute solutions of acids and alkalies, bile salts, chloroform, ether, ammonium sulphocyanid, electricity, etc., also destroy the physical and chemic integrity of the corpuscle and cause the hemoglobin to separate from the stroma and diffuse into the plasma without itself undergoing any appreciable change in composition. With the escape and diffusion of the hemoglobin the blood becomes transparent and changes to a dark red color to which the term "lake color" has been given. The mechanism by which the hemoglobin becomes dissociated and discharged from the corpuscle by these agents is unknown.

The Corpuscles of Other Vertebrated Animals.—In all mammals, with the exception of the camel, llama, and dromedary, the red corpuscles present the same shape and structure as the corpuscles of man, and may be described as circular, flattened, biconcave disks. In the animals excepted the corpuscles are oval. The size, however, varies in different animals from 0.0092 mm. ($\frac{1}{2745}$ inch) in the elephant to 0.0023 mm. ($\frac{1}{12325}$ inch) in the musk-deer, while in most animals the average lies between 0.0084 mm. and 0.0050 mm. Inasmuch as the question may arise as to whether the corpuscles of any given specimen of blood are those of a human being or of some other mammal, a knowledge of the size of the corpuscles becomes a matter of medicolegal as well as of physiologic interest. Though the differences in size are slight, yet it is possible for skilled microscopists, when examining fresh blood, to make a diagnosis between the corpuscles of man and those of the domesticated animals, with the exception, perhaps, of the guinea-pig. The diagnosis of the corpuscles of dried blood which have been altered by the action of various external agents, even though capable of a certain degree of restoration, is most difficult, and should not be attempted in criminal cases without large experience in microscopy, in measurements and methods of preparation of all kinds of blood-corpuscles, and a proper perception of corpuscular forms and sizes. In the following table the average results of the measurements of the corpuscles in different classes of animals are given (abstracted from Formad's compilation):

	GULLIVER.		WORMLEY.		C. SCHMIDT. MALLININ.		FRENCH MEDICOLEGAL SOC. WELCKER.		FORMAD.	
	Inch.	Mm.	Inch.	Mm.	Inch.	Mm.	Inch.	Mm.	Inch.	Mm.
Man, ...	1.3200	0.0079	1.3250	0.0078	1.3300	0.0077	1.3257	0.0078	1.3200	0.0079
Guinea pig, . . .	1.3538	0.0071	1.3223	0.0079	1.3300*	0.0077	1.3213†	0.0079	1.3400	0.0075
Dog, ...	1.3532	0.0071	1.3561	0.0071	1.3636	0.0070	1.3485	0.0073	1.3580	0.0071
Rabbit, ...	1.3607	0.0070	1.3653	0.0070	1.3968	0.0064	1.3653	0.0069	1.3662	0.0069
Ox, ...	1.4267	0.0060	1.4219	0.0060	1.4354	0.0058	1.4545	0.0056	1.4200	0.0060
Pig, ...	1.4230	0.0060	1.4268	0.0059	1.4098	0.0062	1.4098	0.0062	1.4250	0.0060
Horse, ...	1.4600	0.0057	1.4243	0.0059	1.4464	0.0057	1.4545	0.0056	1.4310	0.0059
Cat, ...	1.4404	0.0058	1.4372	0.0058	1.4545	0.0056	1.3922	0.0065	. . .	. . .
Sheep, ...	1.5300	0.0048	1.4912	0.0031	1.5649	0.0045	1.5076	0.0059	1.5000	0.0051
Goat, ...	1.6366	0.0040	1.6189	0.0041	1.6369	0.0040	1.5525	0.0046	1.6100	0.0042

In birds, reptiles, and amphibians the corpuscles are larger than in mammals, are oval in shape, and nucleated. (See Figs. 110 and 111.) As the scale of animal life is descended the corpuscles increase in size, until in the proteus and amphiuma the long diameter attains an average length of 0.058 mm. and 0.077 mm. respectively. In fish the corpuscles are smaller, oval, and nucleated, with the exception of the lamprey eels, in which they are circular, biconcave, and nucleated, though the nucleus is generally concealed in the peripheral portion of the corpuscle. As in these animals, the corpuscles are almost twice the size of the human red corpuscles, they can, notwithstanding the similarity of shape, be readily distinguished from them.

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* Masson.

† Woodward.

The Function of the Red Corpuscles.—The red corpuscles, by virtue of the capacity of their contained hemoglobin for oxygen absorption, may be regarded as carriers of oxygen from the lungs to the tissues, and therefore important factors in the general respiratory process. The size as well as the number of the corpuscles in different classes of animals appears to be directly related to the activity of the respiratory process. In those animals in which the corpuscles are small and numerous and the total superficial area large, respiration is active, the quantity of oxygen absorbed is large, and the energy evolved through oxidation great. In those animals, on the contrary, in which the corpuscles are large and relatively few in number, the reverse conditions obtain. This is in accordance with the fact that the superficial area of any given volume of substance is increased in proportion to the extent to which it is subdivided.

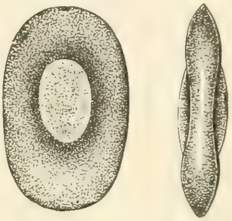

FIG. 110. FIG. 111.
AMPHIBIAN COLORED BLOOD-CORPUSCLES. Fig. 110, on the flat; Fig. 111, on edge. — (*Landois and Stirling.*)

The superficial area of a single human red corpuscle has been estimated at 0.000128 sq. mm. If the number of corpuscles in 1 cubic millimeter of blood averages 5,000,000, the superficial area would amount to 640 square millimeters; and if the amount of blood in the body of a man weighing 75 kilos is taken as one-thirteenth of this weight—that is, 5769 grams (5463 c.c.)—the total area of the corpuscular surface will amount to 3496 square meters.

Life-history of Red Corpuscles.—In the performance of their functions the red corpuscles undergo more or less disintegration and finally destruction; but as the average number is maintained under normal physiologic conditions, there must be a constant renewal of corpuscles from day to day. The evidence of destruction of red corpuscles is furnished by the presence in the blood, in various situations of the body, of a pigment containing iron and the presence of pigments in the bile and urine, all of which are believed to be derivatives of effete hemoglobin. The blood-pigment (hematin), which contains the iron of the hemoglobin, is found in the capillaries of the liver, in the cells of the splenic pulp, and in the marrow of the bones. Whether the presence of the pigment in these organs is a proof that the corpuscles are destroyed here, or whether they are to be regarded merely as agents concerned in the further reduction and elimination of the hematin, is uncertain. The genetic relationship between bile-pigment and hemoglobin is shown by the fact that any artificial destruction of hemoglobin or its injection into the blood is attended by an increase in the quantity of bile-pigment eliminated. It appears also from chemic considerations that the hemoglobin will undergo cleavage into a globulin body and hematin, which by the loss of its iron is readily converted into the bile-pigment, bilirubin. The amount of this latter pigment may therefore be taken as an index of the extent of corpuscular destruction.

This gradual decay of corpuscles as well as the losses occasioned by hemorrhages necessitate a continuous formation of new corpuscles, so that the normal number may be maintained. The rapidity with which corpuscles may be renewed, in the woman at least, is shown by a computation of Mr. Charles L. Mix. A woman loses during a menstrual period 150 c.c. of blood. At the end of twenty-eight or thirty days this volume is restored, so that in one day 5 c.c., or 5000 c.mm., of blood must be formed, or 208 c.mm. per hour and $3\frac{1}{2}$ c.mm. per minute. That is, during a certain number of years 15,750,000 corpuscles must be formed every minute, and this independent of the daily loss due to functional activity.

At the present time there is a general agreement among histologists that in adult life the red corpuscles are derived from embryonic forms, the so-called erythroblasts, which are found chiefly in the red marrow of the long bones.* In this situation both arterial and venous capillaries are relatively large and the blood is separated from the surrounding marrow by extremely thin walls. In the passages of this capillary network the erythroblasts make their appearance most probably by a transformation of pre-existing marrow cells. At first they are large, homogeneous, colorless, perhaps slightly tinged with hemoglobin and distinctly nucleated. They increase in number by karyokinesis and at the same time increase in their hemoglobin content. The nucleus is finally extruded, earrying with it a portion of the perinuclear cytoplasm, after which the remainder of the corpuscle assumes the shape and size of the adult corpuscle and is carried out into the general circulation. After severe hemorrhage the formative processes in the marrow may become so active that erythroblasts make their appearance in the blood-stream before the extrusion of the nucleus has taken place.

CHEMIC COMPOSITION OF RED CORPUSCLES.

Hemoglobin.—The red corpuscle consists of a stroma and a coloring-matter, hemoglobin. The amount of hemoglobin in the normal corpuscle is about 30 per cent. of the total weight, the remaining 70 per cent. consisting of 68 per cent. of water and 2 per cent. of solid matter, *e. g.*, lecithin, cholesterin and inorganic salts. When the corpuscle is freed from water the hemoglobin constitutes about 94 per cent. of the total solids, 32 per cent. In the normal condition of the corpuscle the hemoglobin is in an amorphous condition and is combined in some unknown way with the stroma.

If blood which has been rendered laky, by water or any other of the known agencies, be allowed so slowly evaporate, the dissolved hemoglobin undergoes crystallization. The rapidity with which the crystals form varies in the blood of different animals under similar conditions. According to the ease with which crystallization takes place, Preyer has classified various animals as follows: (1) Very difficult—calf, pigeon, pig, frog; (2) difficult—man, monkey, rabbit, sheep; (3) easy—cat, dog, mouse, horse; (4) very easy—guinea-pig, rat.

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* For an admirable résumé of the various views regarding the origin and formation of red corpuscles see the paper of Mr. Charles L. Mix, Boston Med. and Surg. Journal, 1892, Nos. 11 and 12; also paper by Prof. W. H. Howell, Journal of Morphology, vol. iv, 1892.

The hemoglobin crystals vary in shape according to the blood from which they are obtained (Fig. 112). Those obtained from the guinea-pig are tetrahedral; those from man and most mammals are prismatic rhombs; those from the squirrel are in the form of hexagonal plates. Notwithstanding these slight differences, all forms belong to the same crystal system, with the exception of those from the squirrel.

A simple but very effective method of obtaining blood-crystals suggested by Reichert is to lake defibrinated blood, especially that of the dog, rat, guinea-pig, and horse, with acetic or ethylic ether and then add a solution, 1 to 5 per cent., of ammonium oxalate. A drop of this mixture placed under the microscope will show crystal formation in a very few minutes.

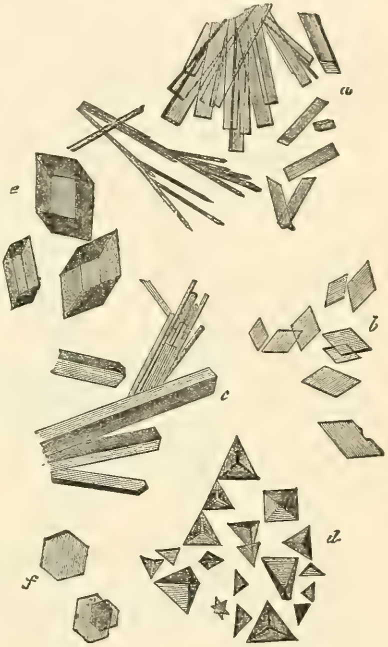


FIG. 112.—CRYSTALLIZED HEMOGLOBIN. *a*, *b*. Crystals from venous blood of man. *c*. From blood of cat. *d*. Of guinea-pig. *e*. Of marmot. *f*. Of squirrel.—(*Gautier*).

Chemic Composition of Hemoglobin.—By appropriate methods hemoglobin can be obtained in a practically pure form, and when subjected to a temperature of 100° C. its water of crystallization is driven off, after which it can be analyzed. In the subjoined table the results of several analyses are given for 100 parts of hemoglobin.

	DOG.	HORSE.	DOG.	GUINEA-PIG.
C,	53.91	51.15	53.85	54.12
O,	22.62	23.43	21.84	20.68
H,	6.62	6.76	7.32	7.36
N,	15.98	17.94	16.17	16.78
S,	0.54	0.39	0.39	0.58
Fe,	0.33	0.33	0.43	0.48
	Jaquet.	Zinoffsky.	Hoppe-Seyler.	

The elementary composition of hemoglobin is thus seen to vary slightly in different animals, suggesting that there may be different kinds of hemoglobin. The rational molecular formula is not known. On the assumption that each molecule contains one atom of iron, Preyer suggested the following empirical formula: $C_{600}H_{960}N_{154}O_{179}S_3Fe$, with a molecular weight of 13,332; Jaquet has suggested a different formula: viz., $C_{758}H_{1203}N_{195}O_{218}S_3Fe$, with a molecular weight of 16.669. It is very evident from this that the molecule is of enormous size and exceedingly complex.

Quantity of Hemoglobin.—The quantity of hemoglobin in blood as determined by chemic, chromometric, and spectro-photometric methods amounts to about 14 per cent. in man and 13 per cent. in woman. Of the chemic methods, that based on the amount of iron is the most familiar. Chemic analysis has shown that hemoglobin contains 0.43 per cent. and blood 0.056 per cent. of iron; with these two factors the quantity of hemoglobin can be determind by thee following formula: $x = \frac{100 \times 0.056}{0.42} = 13.33$ per cent. The total quantity of hemoglobin in the blood, assuming the latter to be about 5769 grams (one-thirteenth of the body-weight, 75 kilos) will therefore amount to 769 grams; *e. g.*, $x = \frac{5769 \times 13.33}{100} = 769$. The total amount of iron in the blood is obtained by the following formula: viz., $x = \frac{5769 \times 0.056}{100} = 3.23$ grams.

Under normal physiologic conditions the percentage of hemoglobin undergoes but slight variation. In pathologic states there is frequently a great diminution in the amount, especially in chlorosis, splenic leukemia, and pernicious anemia, diseases in which it diminishes to 2½ per cent. in many instances. For the determination of these variations in the hemoglobin for clinical purposes two chromometric methods are at present largely employed, that of Gowers and v. Fleischl. All chromometric methods are based on the principle that if two equally thick and equally well-illuminated solutions present the same intensity of color, their richness in coloring-matter is the same. There are two methods by which this can be done: (1) By diluting the blood to be examined with water until the shade of color corresponds to that of a solution of hemoglobin of known strength (Gowers). (2) Diluting a given quantity of blood with a given quantity of water and then finding an identical color which represents a previously determined quantity of hemoglobin (v. Fleischl).

Gowers' hemoglobinometer consists (Fig. 113) of two glass tubes of exactly the same size. One, D, contains glycerin jelly colored with picro-carmine the shade of which corresponds to that of normal blood diluted 100 times, 20 c.mm. in 2000 c.mm. of water representing a 1 per cent. solution. The other tube, C, is ascendingly graduated with 120 divisions, each one of which corresponds to 20 c.mm. With a graduated pipette B 20 cubic millimeters of blood are accurately measured and blown into the bottom of the tube C, in which a few drops of distilled water have been placed so as to prevent coagulation. Water is then added drop by drop until the color of the diluted blood is exactly that of the standard. The division of the scale reached by the dilution will represent the relative percentage of hemoglobin. If this tint is not obtained until the dilution reaches 100 divisions, the quantity of hemoglobin is normal. If more water must be added, it is in excess; if less, it is diminished. If, for example, the 20 cubic millimeters of blood from an anemic patient gave the standard tint at 60 divisions, the blood contained but 60 per cent. of the normal amount of hemoglobin.

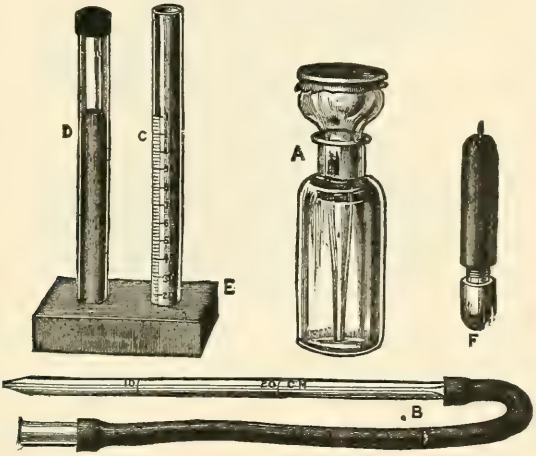


FIG. 113.—GOWERS' HEMOGLOBINOMETER. A. Pipette bottle for distilled water. B. Capillary pipette. C. Graduated tube. D. Tube with standard dilution. F. Lancet for pricking the finger.—(*Landois and Stirling.*)

Von Fleischl's hemometer consists of a metallic cell divided into two compartments, a and a′, by a vertical partition (Fig. 114). In the former a definite quantity of blood is placed and diluted with a known quantity of water. Beneath the compartment a′ is placed a glass wedge stained with the golden purple of Cassius or similar pigment, the color of which passes from a deep red at one end to clear glass at the other (Fig. 115). To the side of this wedge is placed a scale ranging from 0 to 120. By means of the screw, R T, the glass wedge is moved until the color of the glass and diluted blood is identical. The illumination of the blood and glass wedge is accompanied by lamplight reflected from the white reflecting surface beneath. The depth of color of the glass opposite 100 on the scale corresponds to that of normal blood. If, therefore, the colors are identical at 75 divisions, the blood contains but 75 per cent. of hemoglobin.

Very frequently the diminution of corpuscles and hemoglobin proceeds along parallel lines, in which case the amount of hemoglobin per corpuscle is supposed to be normal and the color-index = 1. If the hemoglobin diminution is greater than the corpuscles, as is the case in many pathologic conditions, the color-index is less than unity. If the percentage of corpuscles is determined by the method of counting to be 80 per cent. (4,000,000 per cubic millimeter) and the percentage of hemoglobin 60, the color-index is obtained by dividing the latter by the former; *e. g.*, $\frac{60}{80} = 0.75$. In other words, each corpuscle has but 0.75 per cent. of the normal amount of hemoglobin.

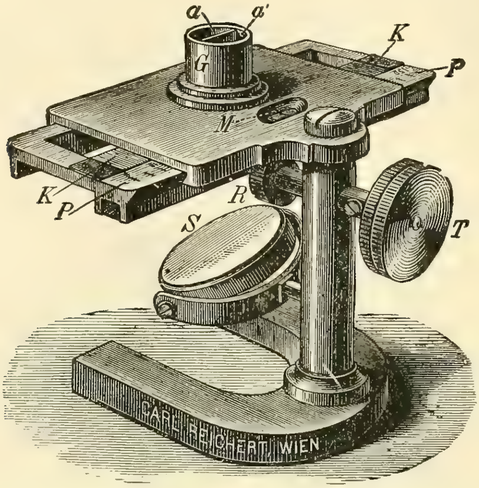


FIG. 114.—VON FLEISCHL'S HEMOMETER. K. Red colored wedge of glass moved by R. G. Mixing vessel with two compartments, *a* and *a'*. M. Table with hole to read off the percentage of hemoglobin on the scale P. T. To move K. S. Mirror of plaster-of-Paris.

Absorption Spectra.—Both oxyhemoglobin and reduced hemoglobin, like other soluble pigments, have an absorbing influence on certain waves of light, and hence give rise to absorption bands which can be studied with the spectroscope, and which are so characteristic as to serve for their identification.

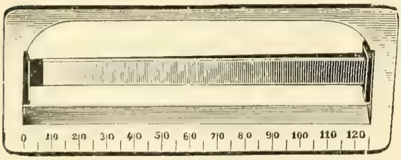


FIG. 115.—TINTED GLASS WEDGE OF THE VON FLEISCHL HEMOMETER.—(*Da Costa's Hematology.*)

In principle a spectroscope consists of a prism which decomposes the light from a narrow slit into a band of all the spectral colors. A form of spectroscope in common use is that shown in Fig. 116. It consists of a tube, B, which has at one end a slit that can be narrowed or widened by means of a screw. The light, having passed through it, falls on an achromatic convex lens (called the collimator)

(Triacid Stain.)

1, 2, 3, 4. **Small Lymphocytes.**
Contrast the faintly colored protoplasm of these cells in the triple stained specimen, with their intensely basic protoplasm in the film stained with eosin and methylene-blue, 17 and 18. The cell body of 1 is invisible. Note the kidney-shaped nucleus in 4.

5, 6. **Large Lymphocytes.**
With this stain the nucleus reacts more strongly than the protoplasm; with eosin and methylene-blue (19, 20), on the contrary, the protoplasm is so deeply stained that the nucleus appears pale by contrast. This peculiarity is also observed in the smaller forms of lymphocytes.

7, 8. **Transitional Forms.**
Note the moderately basic and indented nucleus, and the almost hyaline non-granular protoplasm. Compare 8 with the myelocyte, 7, Plate I, these cells differing chiefly in that the myelocyte contains neutrophile granules.

9, 10, 11. **Polynuclear Neutrophiles.**
These cells are characterized by a polymorphous or polynuclear nucleus, surrounded by a cell-body filled with fine neutrophile granules. In 11 the nuclear structure is obviously separated into four parts; in 9 it is moderately, and in 10 markedly, polymorphous.

12, 13. **Eosinophiles.**
The nuclei are not unlike those of the polynuclear neutrophile, except that they are somewhat less convoluted, and poorer in chromatin, staining less intensely. The protoplasm is filled with coarse eosinophile granules, the characteristics of which are clearly illustrated by 13, a "fractured" eosinophile.

14. **Eosinophilic Myelocyte.**
Compare with 15.

15, 16. **Myelocytes.** *(Neutrophilic.)*
These cells are morphologically similar to 14, except that they contain neutrophile instead of eosinophile granules. Note that the granules of the myelocyte are identical with those of the polynuclear neutrophile. A dwarf form of myelocyte is represented by 16.

(Eosin and Methylene-blue.)

17, 18. **Small Lymphocytes.**
Note the narrow rim of pseudo-granular basic protoplasm surrounding the nucleus, and the pale appearance of the latter.

19, 20. **Large Lymphocytes.**
Budding of the basic zone of protoplasm is represented by 20. Both of these cells belong to the same type as 5 and 6.

21, 22. **Large Mononuclear Leukocytes.**
Compared with 19 and 20, these cells have a decidedly less basic protoplasm, but a somewhat more basic nucleus. In the triple stained film these differences cannot be detected, so that they must be classed as large lymphocytes.

23. **Transitional Form.**
The distinction between this cell and 24 is not marked; the nucleus of the latter simply being somewhat more basic and convoluted.

24, 25, 26, 27. **Polynuclear Neutrophiles.**
With this stain these cells show a feebly acid protoplasm, and lack granules. Note that the more twisted the nucleus the deeper it is stained. Compare with 9, 10, and 11.

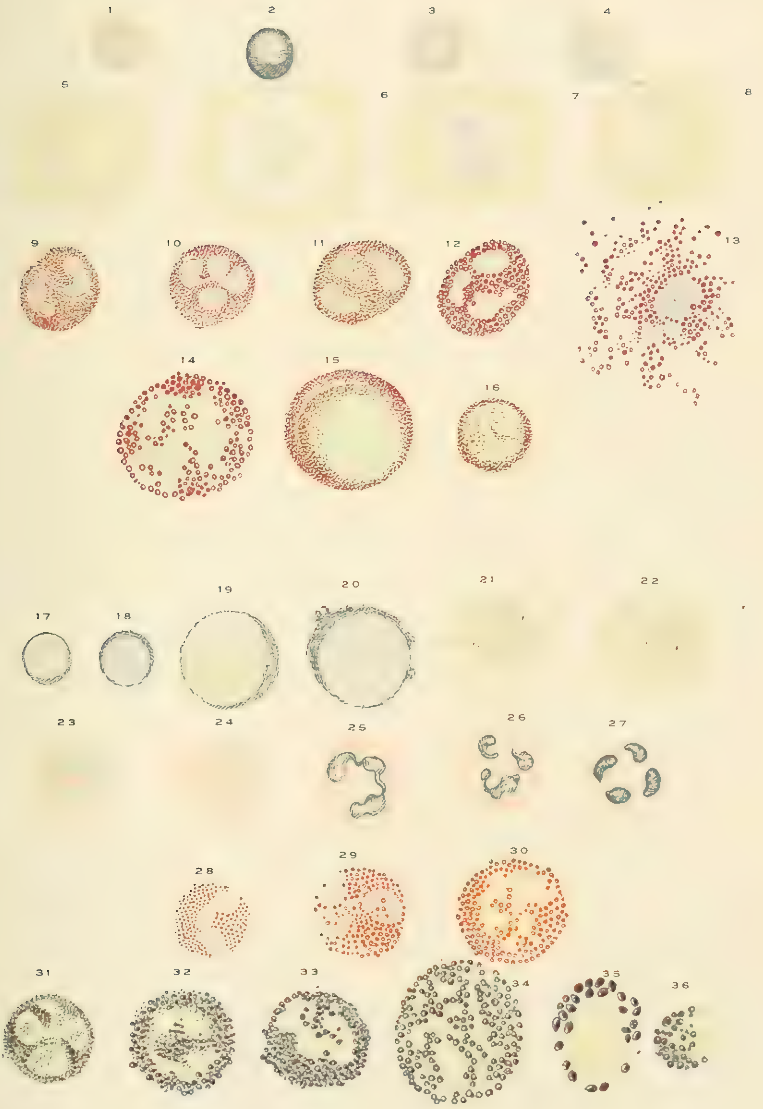
28, 29. **Eosinophiles.**
Compare with 12 and 13.

30. **Eosinophilic Myelocyte.**
Compare with 14

31. **Basophile.** *(Finely granular.)*
This cell is characterized by the presence of exceedingly fine δ-granules, staining the *pure* color of the basic dye. The nucleus is markedly convoluted and deficient in chromatin. The cell here shown was found in normal blood.

32, 33, 34, 35, 36. **Mast Cells.**
The granules take a *modified* basic color, as shown by their royal-purple tint in this illustration. Note their unusually large size and ovoid shape in 35, their peculiar distribution in 35 and 36, and their irregularity in size in 32 and 36. With the triacid mixture these granules, as well as those of the finely granular basophile, 31, remain unstained, showing as dull-white stippled areas in the cell-body. The nuclear chromatin of the mast cell is so delicate and so feebly stained that it is barely visible. These cells were found in the blood of a case of splenomedullary leukemia.

PLATE I.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THE LEUKOCYTES.

(2-16, *Triacid Stain;* 17-36, *Eosin and Methylene-blue.*)

(E. F. FABER, *fec.*)

(*From DaCosta's "Clinical Hematology."*)

at the opposite end of the tube which renders the divergent rays of light parallel. These parallel rays subsequently fall on the prism, by which they are dispersed and directed into the tube, A, which is nothing more than a small telescope. On looking into it at the ocular end the spectral colors are seen. If the light has been derived from the sun, the spectrum will present vertical dark lines, the so-called Fraunhofer's lines. They are given from A to F in Fig. 117. If a colored medium be held in front of the slit so that the light has to pass through it first, certain dark bands will appear in the spectrum, owing to the absorption of certain rays.

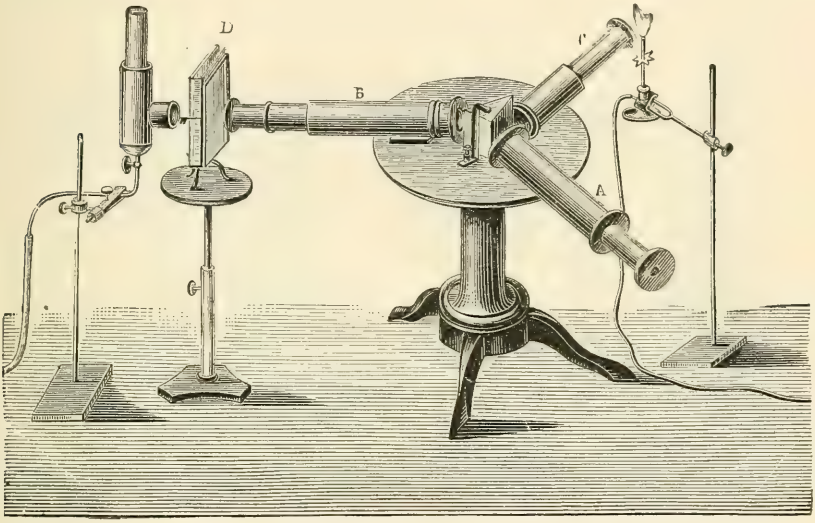

FIG. 116.—THE SPECTROSCOPE. A. Telescope. B. Tube for the admission of light and carrying the collimator. C. Tube containing a scale, the image of which when illuminated is reflected above the spectrum. D. The fluid examined.—(*Landois and Stirling.*)

Dilute solutions of arterial blood show two absorption bands between the Fraunhofer lines, D and E, in the green and yellow portion of the spectrum. (See Fig. 117.) The band nearest D frequently designated as alpha is dark in the center and sharply defined. The band which lies toward E is broader and less sharply defined.

As the amount of light absorbed varies with the concentration of the solution as well as its thickness, and gives rise to absorption bands of different widths and intensities, it becomes necessary, in order to obtain the characteristic bands, to employ only dilute solutions.

The absorption spectra, as seen with different strengths of solution one centimeter thick, are shown graphically in Fig. 118. It will be observed that solutions varying in strength from 0.1 per cent. to 0.6

per cent. give rise to the two characteristic bands, but with gradually increasing breadths. With a percentage greater than 0.65 per cent. the light between D and E, the yellow-green, becomes extinguished and the two bands fuse together, forming a single band overlapping slightly the lines D and E. At the same time there is a progressive darkening of the violet end of the spectrum. At 0.85 per cent., all the light is absorbed with the exception of a small amount of the red.

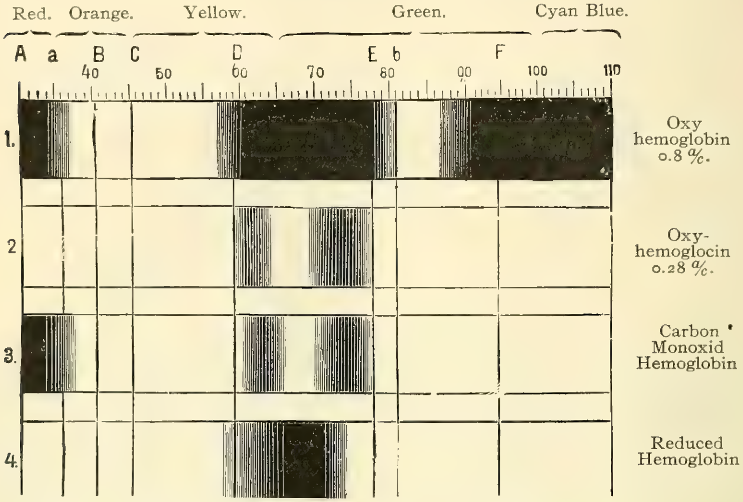

FIG. 117.—SPECTRA OF HEMOGLOBIN AND SOME OF ITS COMPOUNDS. —(*Landois and Stirling.*)

Solutions less than 0.01 per cent. to 0.003 per cent. show but a single absorption band—that nearest D.

A solution of venous blood or of reduced hemoglobin shows but a single absorption band (see Fig. 117), frequently designated as gamma, broader and less marked between the lines D and E, but extending slightly beyond D. Fig. 117 shows in the same graphic manner the increasing breadth of the absorption band with increasing strengths of solution, as well as the simultaneous absorption of light at both the red and violet ends of the spectrum.

Compounds of Hemoglobin.—The coloring-matter of the blood is characterized by the property of combining with and of again yielding up oxygen. The union is a chemic one, taking place under certain pressure conditions. It therefore may exist in two states of oxidation, distinguished by a difference in color and their absorption spectra. If hemoglobin either in blood or in solution be shaken with air, it at once combines with oxygen and is converted into oxyhemoglobin, which imparts to the blood or solution a bright red or scarlet color. If the blood or solution be now deprived of oxygen, the oxyhemoglobin is converted into reduced hemoglobin, which imparts to the blood or solution a dark bluish or purple color.

The quantity of oxygen absorbed by 1 gram of hemoglobin is estimated at 1.56 c.c. measured at 0° C. and 760 mm. of mercury. The compound formed by the union of oxygen and hemoglobin is a very feeble one; for when the pressure is lowered the union becomes less stable, and as the zero point is approached, as in the Torricellian vacuum, a rapid dissociation of the oxygen takes place. This, however, is not due entirely to a fall of pressure but partly to the dissociating force of heat, which increases in power as the pressure falls.

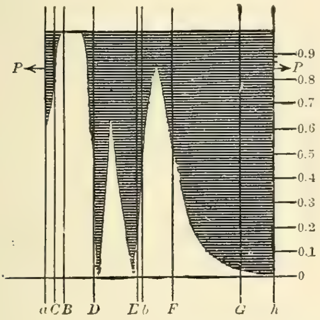

FIG. 118.—GRAPHIC REPRESENTATION OF THE ABSORPTION OF LIGHT IN A SPECTRUM BY SOLUTIONS OF OXYHEMOGLOBIN OF DIFFERENT STRENGTHS. The shading indicates the amount of absorption of the spectrum, and the numbers at the side the strength of the solution.

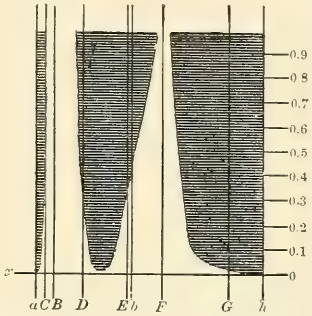

FIG. 119.—GRAPHIC REPRESENTATION OF THE ABSORPTION OF LIGHT IN A SPECTRUM BY SOLUTIONS OF HEMOGLOBIN OF DIFFERENT STRENGTHS. The shading indicates the amount of absorption of the spectrum, and the numbers at the side the strength of the solution.

The same dissociation of oxygen can be brought about by passing through blood indifferent gases, such as hydrogen, nitrogen, carbon dioxid, which lower oxygen pressure, or by the addition of reducing agents, such as ammonium sulphid or Stokes' fluid.

These experimental determinations of the relation of oxygen to hemoglobin partly explain the oxidation and deoxidation of the hemoglobin in the lungs and tissues. As the blood passes through the lungs and is subjected to the oxygen pressure there, the hemoglobin combines with a definite quantity of oxygen, and on emerging from the lungs exhibits a bright red or scarlet color; as the blood passes through the systemic capillaries where the oxygen pressure in the surrounding tissues is low, the oxyhemoglobin yields up a portion of its oxygen, becoming deoxidized or reduced, and the blood on emerging from the tissues exhibits a dark bluish color. The portion of oxygen given up to the tissues is termed respiratory oxygen. In 100 parts of arterial blood the coloring-matter presents itself almost exclusively in the form of oxyhemoglobin. In passing through the capillaries about 5 per cent. only gives up its oxygen and becomes reduced, so that both kinds are present in venous blood. In asphyxiated blood only reduced hemoglobin is present. It is this capability of combining with and of again yielding up oxygen, that enables hemoglobin to become the carrier of oxygen from the lungs to the tissues.

Carbon Monoxid Hemoglobin.—Carbon monoxid is a constituent of both coal-gas and water-gas. From either source it is likely to accumulate in the air, and if inspired for any length of time produces a series of effects which may eventuate in death. If blood be brought into contact with this gas, it assumes a bright cherry-red color, which is quite persistent and due to the displacement of the loosely combined oxygen and the union of the carbon monoxid with the hemoglobin. The compound thus formed is very stable and resists the action of various reducing agents. The passage of air or of some neutral gas through the blood for a long period of time will gradually displace the carbon monoxid and enable the hemoglobin to again absorb oxygen. It is for this reason that partial poisoning with the gas is not fatal. It is to its power of displacing oxygen and forming a stable compound with hemoglobin and thus interfering with its respiratory function that carbon monoxid owes its poisonous properties. Examined spectroscopically, solutions of carbon monoxid hemoglobin exhibit two absorption bands closely resembling in position and extent those of oxyhemoglobin; but careful examination shows that they are slightly nearer the violet end of the spectrum and closer together. (See Fig. 117.) A useful test for CO blood is the addition of caustic soda, which produces a cinnabar red precipitate.

Methemoglobin.—This is a pigment, closely related to oxyhemoglobin, found in the blood after the administration of various drugs, in cysts and in the urine in hematuria and hemoglobinuria. It is also produced when a solution of hemoglobin is exposed to the air and becomes acid in reaction and brown in color. The spectrum shows two absorption bands similar to oxyhemoglobin, but in addition a new and quite distinct band near the line C, in the red. If the acid solution be rendered alkaline by the addition of ammonia, this band disappears and another makes its appearance near the line D. The addition of ammonium sulphid develops reduced hemoglobin, which, on the absorption of oxygen, produces again oxyhemoglobin, as shown by the spectroscope.

Hematin.—Boiling hemoglobin or adding to it acids or alkalies decomposes it and develops one or more proteid bodies to which the general term globulin has been given, and an iron-holding pigment termed hematin. This is regarded as an oxidation product of hemoglobin and constitutes about 4 per cent. of its composition. When obtained in a pure state, it is a non-crystallizable blue-black powder with a metallic luster. According as it is treated with acids or alkalies, two forms of hematin can be obtained (acid and alkaline), each of which has special properties, giving rise to different absorption bands.

Hemochromogen.—This pigment is derived from hemoglobin, of which it constitutes about 96 per cent., during decomposition in the absence of oxygen. In solution it produces a purple color, but soon absorbs oxygen and is converted into hematin.

Hemin.—This pigment is a derivative of hematin, presenting itself in the form of microscopic rhombic plates or rods (Teichmann's crystals), which are so characteristic as to serve as tests for blood-stains in medicolegal inquiries. These crystals are readily obtained by adding to a small quantity of dried blood on a glass slide a few drops of glacial acetic acid and a crystal of sodium chlorid; after heating gently for a few minutes over a spirit lamp and then allowing the mixture to cool, crystallization of the hemin soon takes place.

Hematoidin.—This term has been applied to a pigment which occurs in the form of yellow crystals in old blood-clots or in blood which has been extravasated into the tissues. In its chemic composition and in its reactions it closely resembles bilirubin, the pigment of the bile, exhibiting the same characteristic play of colors on the addition of nitric acid.

The Stroma.—The stroma of the red corpuscles obtained by the methods which dissolve out the hemoglobin has been shown by analysis to consist of from 60 to 70 per cent. of water and 40 to 30 per cent. of solid material, containing a proteid resembling cell-globulin, lecithin, cholesterin, and inorganic salts, among which potassium phosphate is especially abundant.

HISTOLOGY OF THE WHITE CORPUSCLES OR LEUKOCYTES.

The presence of white corpuscles in the blood can be readily observed under the same conditions as the red corpuscles are observed. Thus when the mesentery of the frog or the guinea-pig is examined with the microscope the white corpuscles are seen adhering to the walls of the blood-vessels; in a drop of freshly drawn blood they are found in the spaces between red corpuscles (Fig. 104).

Shape and Size.—In the resting condition, whether seen in the vessel or on the stage of the microscope, the white corpuscle, as its name implies, is grayish in color, round or globular in form, though often presenting a more or less irregular surface. Its diameter varies from 0.0004 to 0.0013 mm., though the average is about 0.0011 mm. or about $\frac{1}{2500}$ inch.

Structure.—A typical white corpuscle consists of a ground-substance uniformly transparent and apparently homogeneous, in which are embedded a number of granules of varying size, some of which are very fine, while others are larger. By various reagents it has been demonstrated that the granules are fatty, proteid, and carbohydrate (glycogen) in character. In the fresh cells the existence of a nucleus is difficult of detection, though its presence can be demonstrated by the addition of acetic acid, which renders the perinuclear cytoplasm more transparent and makes the nucleus conspicuous and sharply defined. From its structure it is apparent that the white corpuscle belongs to the group of undifferentiated tissues and resembles the cells of the embryo in its earliest stages as well as the unicellular organism, the amœba.

Chemic Composition.—The chemic composition of the white corpuscles has been inferred from an analysis of pus-corpuscles, with which they are practically identical, and of lymph-corpuscles from the lymph-glands. Of the corpuscle about 90 per cent. is water and the remainder solid matter consisting mainly of proteids, of which nuclein, nucleo-albumin, and cell globulin are the most abundant. The two former are characterized by the presence of a considerable quantity of phosphorus, amounting to as much as 10 per cent. Lecithin, fat, glycogen, and earthy and alkaline phosphates are also present.

Number of White Corpuscles.—The number of white corpuscles per cubic millimeter of blood is much less than the number of red corpuscles, the ratio being in the neighborhood of 1 white to 700 red. This ratio, however, varies within wide limits in different portions of the body and under normal variations in physiologic conditions. In the blood of the splenic artery there is but 1 white to 2260 red, while in the splenic vein there is 1 white to every 60 red; or about thirty-eight times as many as in the artery. In the portal vein there is 1 white to 740 red, while in the hepatic vein there is 1 white to 170 red.

The total number of white corpuscles per cubic millimeter has been estimated at from 5000 to 10,000, though the average is about 7500. The number, however, is influenced by a variety of physiologic conditions. The ingestion of food rich in proteid material raises the count from 30 to 40 per cent., as compared with the count before the meal. Fasting for a few days always lowers the count, and in a case of total abstinence of food for a week, reported by Luciani, the count fell to 861 per cubic millimeter, after which it rose to 1530, where it practically remained for the succeeding three weeks of the fasting period. In the new-born the number is greater than in adults —17,000 to 20,000 per cubic millimeter. Cabot states that 30,000 is never a high count after a meal in infants under two years. In the later months of pregnancy, especially in primiparæ, the number increases to 16,000 to 18,000. Many pathologic conditions of the body also influence the count very considerably.

The method for counting the white corpuscles is similar to that used in counting the red. The given volume of blood should, however, be diluted with 10 or 20 volumes of a one per cent. solution of acetic acid, which disintegrates the red corpuscles and thus facilitates the counting of the white. The pipette should have a larger bore than that used for the red, and a much greater number of squares in the counting chamber should be counted, so as to diminish the percentage of error.

Physiologic Properties.—The white corpuscles possess the characteristic property of exhibiting movements similar to those observed in the amœba, and are therefore termed amœboid. These movements consist in alternate protrusions and retractions of portions of the cell body, as a result of which they exhibit a great variety of forms. (See Fig. 120.) The protruded process can also attach itself to some point of the surface on which it rests, and then draw the body of the corpuscle after it. By a repetition of this process the corpuscle can slowly creep about and change its position in space. In virtue of these ameboid movements the corpuscle can appropriate small particles of pigment, such as indigo or carmine, and after a short time eliminate them from various parts of the surface. It is also capable of thrusting a process into and through the wall of the capillary vessel, after which the remainder of the corpuscle follows (Fig. 121). This continues until the corpuscle is outside the vessel and in the lymph-space, where it resumes its original shape and movement. This process is best observed in inflammatory conditions, when the blood has come to rest and the vessels are occluded with both red and white corpuscles. To this passage of the white blood-corpuscles through the capillary wall the term *diapedesis* is given. The movements of the white corpuscles are increased by a rise in temperature up to 40° C., beyond which they cease, owing to the coagulation of the cell-substance. A low temperature also arrests the movements. Induced electric currents also cause contraction and death of the cell. Moisture and oxygen are necessary to their activity. From their similarity to lower organisms the white corpuscles may be regarded as independent organisms living in the animal fluids, just as the amœba lives in its natural liquid medium.

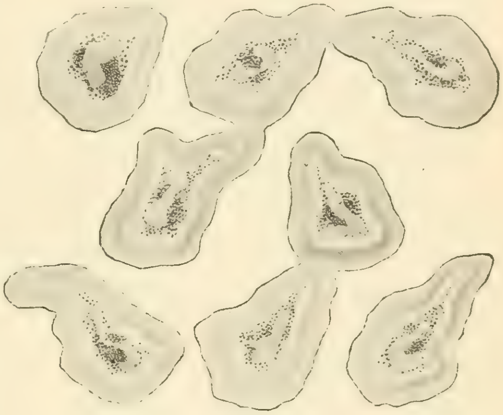

FIG. 120—HUMAN LEUKOCYTES SHOWING CHANGES OF SHAPE DUE TO AMŒBOID MOVEMENTS. (*G. Bachman.*)

Varieties of Leukocytes.—A detailed study of the blood with the aid of the triacid staining fluid of Ehrlich or any of the various eosin and methylene-blue stains, reveals the presence of five distinct varieties of leukocytes and transitional forms which may be classified as follows:

1. *Small lymphocytes*, so called from their resemblance to the corpuscles of the lymph-glands, consisting of a deeply staining and relatively large round nucleus, encircled by a narrow rim of cytoplasm. Found in from 20 to 25 per cent. of all leukocytes.
2. *Large lymphocytes* or hyaline cells, which are believed by some to represent the preceding type at a later stage of development, by others to have an independent origin, are distinguished by a round or ovoid nucleus staining faintly and surrounded by a relatively larger layer of cytoplasm than is seen in the small lymphocyte. The large lymphocyte is present to the extent of from 4 to 8 per cent. The transitional forms are very much like the large lymphocyte in appearance and size, with the exception, however, that they possess a crescentic or indented nucleus having a somewhat greater affinity for basic dyes. They are usually counted with the large lymphocytes.

   Both varieties of lymphocytes are characterized by a cytoplasm which is devoid of granules. Rarely, basophilic granules may be present.
3. *Polymorphonuclear leukocytes* or *neutrophiles*. The nucleus of this cell is irregular and assumes a great variety of shapes in different cells, a feature which has suggested the name given to the cell. The perinuclear cytoplasm contains a large number of fine granules which are neutrophilic or faintly acidophilic in their staining reaction. They make up about 60 to 70 per cent. of the whole number of the white blood-cells.
4. *Eosinophile cells*. The nucleus resembles in many respects that of the preceding variety; it is, however, less apt to stain so deeply. It is also very irregular in shape and many cells possess several apparently distinct nuclei. The cytoplasm is ill-defined but its presence is easily revealed through the large, intensely acidophilic granules which it possesses.

   It is present to the extent of 0.5 to 2 per cent.
5. *Basophile cells*, the nucleus of which is round or slightly irregular. The granules which may be large or small are basophilic and stain more deeply than the nucleus, though they have the same color. It is rare for this cell to be present above 0.5 per cent. of all leukocytes.

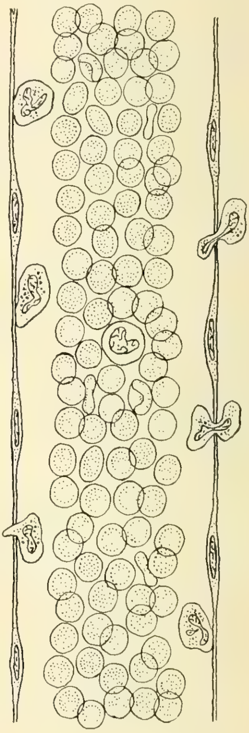

FIG. 121.—SMALL VESSEL SHOWING VARIOUS STAGES IN THE DIAPEDESIS OF LEUKOCYTES. (*G. Bachman.*)

Origin of the White Corpuscles.—Of the various theories advanced to explain the origin of leukocytes, that formulated by Ehrlich has found the most credence. According to this theory the leukocytes may genetically be classed into two groups. In the first group are the large and small lymphocytes which take their origin entirely from the lymph-adenoid tissues of the body, *e.g.*, the lymph-glands, solitary and agminated follicles of the intestines, etc. As the lymph flows through these structures the lymph-corpuscles, as the future lymphocytes of the blood are called in these situations, are washed out and carried by way of the lymph-stream into the general circulation.

In the second group are the transitional forms, the polymorphonuclear, eosinophile and basophile leukocytes which originate from the bone-marrow only. The immediate ancestors of these cells are known as myelocytes and are normally found in the red bone-marrow. These cells, through transitional stages, assume the characteristics of the leukocytes just mentioned and pass directly into the capillaries of the marrow whence they are distributed throughout the body.

Several attempts have been made by different investigators to trace all varieties of leukocytes to a common mother cell. While this is believed to take place during embryonal life, the proofs of such an origin of leukocytes in the normal adult are insufficient and unconvincing.

After an unknown period of life the leukocytes undergo dissolution and disappear.

Functions.—The functions of the white corpuscles are but imperfectly known, and at present no positive statements can be made. It has been suggested that wherever found in the body, whether in blood or tissues, they are engaged in the removal of more or less insoluble particles of disintegrated tissues, in attacking and destroying more or less effectively various forms of invading bacteria and thus protecting the body against their deleterious activity. This they do by surrounding, enveloping, and incorporating either the tissue particle or bacterium and digesting it. On account of this swallowing action these cells were termed by Metchnikoff *phagocytes* and the process *phagocytosis*. The cells engaged in this process are the polymorphonuclear leukocytes and the large and the small lymphocytes. He regards them as the general scavengers of the body. It has been suggested that they are also engaged in the absorption of fat from the lymphoid tissue of the intestine. In their dissolution they contribute to the blood-plasma certain proteid materials which assist under favorable circumstances in the coagulation of the blood.

HISTOLOGY OF THE BLOOD-PLATES.

The blood-plates or plaques are small histologic elements circulating in the blood-plasma. They were discovered by Hayem, who applied to them the term hematoblasts, on the supposition that they were the early stages in the development of the red corpuscles. This is now known to be erroneous. On account of their specific, distinct characters, and their constant presence in the blood of living animals (guinea-pig and bat), they are now regarded as normal constituents of the blood and designated as the third corpuscle. When blood is freshly drawn from the body, the plaques rapidly undergo disintegration and disappear; but by treating the blood with osmic acid, the form and structure of the plaque may be retained.

The blood-plaque may be defined as a colorless, grayish-white, homogeneous or finely granular protoplasmic disk, varying in diameter from 1.5 to 3.5 micro-millimeters. The edges are rounded and well defined, but it is not certain whether they are only flattened or are slightly biconcave. There is, however, no nucleus. The ratio of the plaques to the red corpuscles is 1 to 18 or 20, and the total number per cubic millimeter has been estimated to be 250,000 to 300,000.

When blood is shed they tend to adhere to each other and form irregular masses known as Schultze's granular masses. If threads are suspended in blood, the plaques accumulate in enormous numbers upon them and appear to form a center from which fibrin filaments radiate as coagulation proceeds. The white thrombi which form in blood-vessels in consequence of diseased states—*e. g.*, endocarditis, atheromatous ulceration, etc.—are composed very largely of blood-plaques and fibrin threads. The function of the blood-plaques is unknown, but it has been surmised that in some way they are, like the leukocytes, concerned in the coagulation of the blood. Whenever they are diminished in number, as in purpura and hemophilia, coagulation takes place very slowly.

The blood-plaques can be seen with high powers of the microscope in the blood-vessels of the omentum of the guinea-pig and rat, especially when the blood-stream begins to slow. They are also readily seen in the blood-vessels of subcutaneous connective tissue of various animals, and especially in that of the new-born rat. A small quantity of this tissue moistened with normal saline and examined microscopically with suitable powers will show large numbers of plaques within the blood-vessels.

THE TOTAL QUANTITY OF THE BLOOD; ITS GENERAL COMPOSITION.

The determination of the total quantity of the blood in an animal is best made by the chromometric method, somewhat modified at present, of Welcker. This consists, first, in bleeding an animal, collecting all the blood it yields, and weighing it; second, in washing out the vessels with a normal saline solution until the fluid comes from the veins clear and free from blood; third, in mincing the tissues of the body, after removal of the contents of the alimentary canal, soaking them in water for twenty-four hours, and then expressing them. All the washings are collected and weighed. A given volume of the normal defibrinated blood, treated with carbon monoxid so as to give it uniform color, is then diluted with water until its tint is identical with that of the washings similarly treated with carbon monoxid. From the quantity of water necessary to dilute the blood the quantity of blood in the washings is readily determined. The animal having been previously weighed and the weight of the contents of the alimentary canal deducted, the ratio of the total weight of the blood to the weight of the body at once becomes apparent. By this method it has been shown that the ratio of blood to body-weight in a human adult is 1:13; in an infant, 1:19; in a dog, 1:13; in a cat, 1:21. Thus an adult man of 75 kilos weight would have 5769 grams of blood.

The amount of blood in the different organs has been determined by ligating the blood-vessels in the living animal, removing the organ, and after allowing the blood to escape subjecting the tissues to the chromometric methods described above. According to Ranke, the volume of the blood is distributed as follows: Heart, lungs, arteries, and veins, $\frac{1}{4}$; liver, $\frac{1}{4}$; muscles, $\frac{1}{4}$; other organs, $\frac{1}{4}$.

General Composition.—The results of the analyses of the blood will vary with the animal and the methods employed. The following table, taken from Gad, shows the average composition, expressed in whole numbers, of horse's blood. In essential respects the ratio of the constituents in human blood would not be materially different.

One thousand parts of blood contain:

Cells,	328	Water,	200		200
		Solids,	128	Hemoglobin,	116
				Other organic matter,	10
				Salts,	2
Plasma,	672	Water,	604		604
		Solids,	68	Fibrin,	7
				Albumin,	52
				Fat,	1
				Other organic matter,	3
				Potassium and sodium salts,	4
				Calcium and magnesium salts,	1

CHEMISTRY OF COAGULATION.

The changes which eventuate in the formation of fibrin, and hence all the subsequent phenomena of coagulation, are chemic in character; but as these changes take place in organic compounds the composition of which is but imperfectly known, the intimate nature of the process is quite obscure. All the theories which have been advanced in explanation, though approximating the truth, are more or less incomplete and in some respects contradictory. Since the coagulation is coincident with the appearance of the fibrin, the antecedents of this substance, the physical and chemic conditions which condition its development, and the succession of chemic changes involved must be determined, before any consistent theory can be established.

Extra-vascular Coagulation.—At present it is generally believed that the immediate factors concerned in extra-vascular coagulation are fibrinogen, a calcium salt, and a ferment-body. As to the manner in which these three bodies react one with another there is a diversity of opinion. At least five different theories are current at the present time, all of which have some features in common, though presenting points of difference.

Alexander Schmidt long contended that fibrin was the result of a union of fibrinogen and paraglobulin; that the union was brought about by a ferment-body; that the presence of the neutral salts of the plasma was necessary to the activity of the ferment. Previous to his death in 1893 Schmidt modified his view as follows: The insoluble fibrin is developed out of a soluble fibrin derived from paraglobulin, which in turn is a product of general cell disintegration; the conversion of the fibrinogen into fibrin is due to the activity of a ferment, *thrombin*, a derivative of pro-thrombin, a product of the disintegration of leukocytes, lymph-cells, etc.; that the production of thrombin is conditioned by the presence of the neutral salts of the plasma in normal percentages; that no one of these salts, calcium included, acts in a specific manner; finally, that fibrin is not a compound of a proteid and calcium.

Hammersten, as a result of many years of investigation, believes that paraglobulin is not necessary to the process, fibrinogen alone being transformed into fibrin under the influence of the ferment, in the presence of a neutral salt, especially calcium, which acts specifically in a manner different from the sodium salts. Inasmuch as the quantity of fibrin produced is always less than the quantity of fibrinogen previously present, Hammersten concludes that the latter substance, under the influence of the ferment, undergoes a cleavage into two unequal portions, one of which remains in solution, the other solidifying as fibrin. While admitting that the calcium salts act specifically, he believes that they are concerned rather with the production of the ferment than the fibrin, for if the ferment is present in sufficient quantity coagulation takes place in a typical manner even in the total absence of calcium.

Arthus and Pagés conclude that for the transformation of fibrinogen into fibrin the calcium salts are absolutely essential and act in a specific manner; that the ferment causes a cleavage of fibrinogen into two substances, one of which remains in solution, the other combines with calcium to form fibrin. They offer in support of this view the fact that if a 1 per cent. solution of potassium oxalate be added to blood in quantity sufficient to precipitate the calcium, coagulation will not take place; but if calcium is restored coagulation proceeds in the usual manner. They transfer the sphere of influence of calcium to the formation of the fibrin rather than to the formation of the ferment.

Pekelharing's researches led him to the conclusion that there arises from the disintegration of the leukocytes a nucleo-proteid, pro-thrombin, which combining with the calcium salt forms the ferment thrombin. This compound then transfers the calcium to the fibrinogen, which in turn becomes fibrin; the latter is therefore a proteid-calcium compound.

Lilienfeld asserts that fibrin formation is a cleavage process by which fibrinogen is separated into two bodies, one an albumose which remains in solution, the other a proteid to which he has given the name *thrombosin.* This cleavage is attributed to the action of the usual ferment, a product of the disintegration of leukocytes. Thrombosin combines, according to Lilienfeld, with calcium to form fibrin.

In a critical examination of these different theories Hammersten denies that fibrin is a compound of a proteid and calcium; for chemic analysis of both fibrinogen and fibrin shows that the former contains as much calcium as the latter, and that therefore the view of coagulation according to which fibrinogen unites with calcium to form fibrin is without foundation. On the contrary, he maintains that the specific influence of the calcium is directed toward the production of the ferment, for if this be present in sufficient quantity coagulation takes place in a typical manner, no matter whether the blood has been decalcified by potassium oxalate or not.

Intra-vascular Coagulation.—So long as the relations of the blood and the vascular system remain physiologic no coagulation occurs in the vessels. The reason assigned for this is that the ferment, though continually being produced, is as rapidly being destroyed, and hence never accumulates in amount sufficient to develop fibrin. This view is supported by the fact that if a solution of cell-protoplasm, leukocytes, lymph-corpuscles, etc., presumably containing a large amount of the ferment, be injected into the blood-vessels, extensive intra-vascular coagulation promptly follows. It is also believed that the lining of the blood-vessel in some unknown way restrains the coagulation process even though the circulation has come to rest.

Under pathologic conditions of the circulatory apparatus, especially of the internal lining, intra-vascular coagulation frequently arises, though the process can not be considered as identical with extra-vascular coagulation. Many pathologists assert that in its origin, mode of formation, and structure the intra-vascular coagulum or thrombus is not a true coagulum as ordinarily understood, but rather a conglutination of blood-plaques and leukocytes. Whenever the integrity of the internal wall of the vessel is impaired by disease or by the introduction of foreign bodies, there is primarily a deposition and accumulation of blood-plaques at the injured area or on the foreign body which constitutes to a large extent the mass of the thrombus which at once forms. The thrombi which form on the surface of atheromatous ulcers, on the valves of the heart, and in the veins in consequence of diseased states, on threads or needles passed through the vessels, at the orifices of torn blood-vessels, consist largely of blood-plaques. A thrombus so formed may contain a number of delicate fibrin threads, which, however, present a different appearance from the fibrin of the extra-vascular clot. In the thrombi which form around foreign bodies there is always a larger quantity of fibrin than in those originating from causes wholly within the vessel.

CHAPTER XIII.

THE CIRCULATION OF THE BLOOD.

Each organ and tissue of the body is the seat of a more or less active metabolism, the maintenance of which is essential to its physiologic activity. This metabolism is characterized by the assimilation of food materials and the production of waste products; that it may be maintained it is imperative that there shall be a continuous supply of the former and a continuous removal of the latter. Both conditions are subserved by the blood. In order, however, that this fluid may fulfil these functions it must be kept in continuous movement, must flow into and out of the tissues in volumes varying with their activity, under a given pressure and with a certain velocity.

The apparatus by which these results are attained is termed **the circulatory apparatus.** This consists of a central organ, the heart; a series of branching diverging tubes, the arteries; a network of minute passageways with extremely delicate walls, the capillaries; a series of converging tubes, the veins. These structures are so arranged as to form a closed system of vessels within which the blood is kept in continuous movement mainly by the pressure produced by the pumping action of the heart, though aided by other forces. (See Fig. 122.)

In this system a particle of blood which passes any given point will eventually return to the same point, no matter how intricate or tortuous the route may be through which it in the meanwhile travels; for this reason the blood is said to move in a circle, and the movement itself is termed the circulation.

In order to understand the reasons for the movement of the blood in one direction only, as well as for many other phenomena connected with the circulation, a knowledge of the structure of the heart and its internal mechanism is of primary importance.

THE PHYSIOLOGIC ANATOMY OF THE HEART.

The heart is a cone or pyramid-shaped hollow muscular organ situated in the thorax just behind the sternum. The base is directed upward and to the right side; the apex downward and to the left side, extending as far as the space between the cartilages of the fifth and sixth ribs. In this situation the heart is enclosed and suspended in a fibroserous sac, the *pericardium*, attached to the great vessels at its base.

The heart is a hollow, double organ, consisting of a *right* and a *left* half, separated by a musculo-membranous septum. The general cavity of each side is subdivided by an incomplete transverse fibrous septum into two smaller cavities, an upper and a lower, known respectively as the *auricle* and the *ventricle*. The heart may therefore be said to consist of four cavities, the walls of which are composed of muscle-tissue. Of these four cavities, the right auricle and the right ventricle constitute the *venous* heart; the left auricle and the left ventricle, the *arterial* heart.

The right auricle is quadrangular in shape and presents on its posterior aspect two large openings, the terminations of the two final trunks of the venous system, the *superior* and *inferior venæ cavæ* (Fig. 123). Below, the auricle communicates with the ventricle by a large opening which, from its position, is termed the *auriculo-ventricular* opening. The walls of the auricle are extremely thin, not measuring more than two millimeters in thickness.

The right ventricle, as shown on cross-section, is crescentic in shape owing to the projection of the ventricular septum. It presents at its upper left angle a cone-shaped prolongation, the *conus arteriosus*. From this prolongation, and continuous with it, arises the pulmonary artery. The wall of the ventricle measures in the middle about four millimeters in thickness. The inner surfaces of the ventricle show: (1) a complicated system of muscle ridges and bands, the *columnæ carneæ* (fleshy columns), and (2) a set of muscle projections, the *musculi papillares* (papillary muscles), which arise by a broad base from the walls of the ventricle and project upward toward the auriculo-ventricular opening. From the apex of each papillary muscle there are given off fine tendinous cords, the *chordæ tendineæ*, which become attached above to the under surface of the auriculo-ventricular valve.

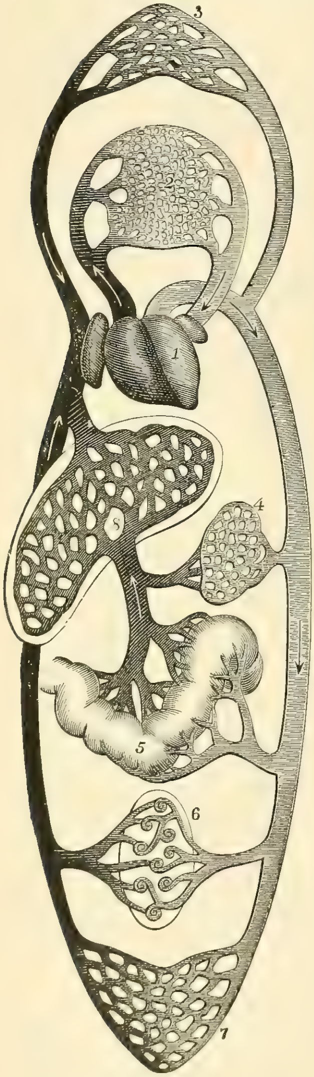

FIG. 122.—DIAGRAM OF CIRCULATION. 1. Heart. 2. Lungs. 3. Head and upper extremities. 4. Spleen. 5. Intestine. 6. Kidney. 7. Lower extremities. 8. Liver. —(*Dalton.*)

The left auricle, similar in general shape to the right, presents posteriorly four openings, the terminations of the four final trunks of the venous system of the lungs, the pulmonary veins. Below is found the corresponding auriculo-ventricular opening. The wall of the auricle measures about 3 mm. in thickness. The left ventricle (Fig. 124) is conic in shape from above downward and oval or circular in shape on cross-section. At its upper right angle it presents a circular orifice, the margins of which give attachment to the walls of the aorta, the main arterial trunk of the systemic circulation. The inner surfaces of the ventricle show a similar though better developed system of columnæ carneæ, musculi papillares, chordæ tendineæ,

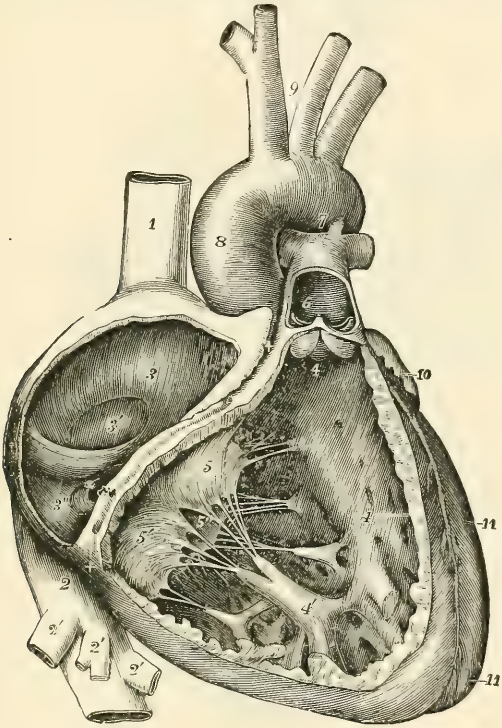

FIG. 123.—THE RIGHT AURICLE AND VENTRICLE OPENED, AND A PART OF THEIR RIGHT AND ANTERIOR WALLS REMOVED, SO AS TO SHOW THEIR INTERIOR. ½—1. Superior vena cava. 2. Inferior vena cava. 2'. Hepatic veins cut short. 3. Right auricle. 3'. Placed in the fossa ovalis, below which is the Eustachian valve. 3''. Is placed close to the aperture of the coronary vein. + +. Placed in the auriculo-ventricular groove, where a narrow portion of the adjacent walls of the auricle and ventricle has been preserved. 4, 4. Cavity of the right ventricle; the upper figure is immediately below the semilunar valves. 4'. Large columna carnea or musculus papillaris. 5, 5', 5''. Tricuspid valve. 6. Placed in the interior of the pulmonary artery, a part of the anterior wall of that vessel having been removed, and a narrow portion of it preserved at its commencement, where the semilunar valves are attached. 7. Concavity of the aortic arch close to the cord of the ductus arteriosus. 8. Ascending part or sinus of the arch covered at its commencement by the auricular appendix and pulmonary artery. 9. Placed between the innominate and left carotid arteries. 10. Appendix of the left auricle. 11, 11. The outside of the left ventricle, the lower figure near the apex.—(*Allen Thomson.*)

etc. The wall of the left ventricle measures about 11.5 mm. in thickness in the middle.

The Endocardium.—The cavities of both the right and left sides of the heart are lined by a thin firm connective-tissue membrane,

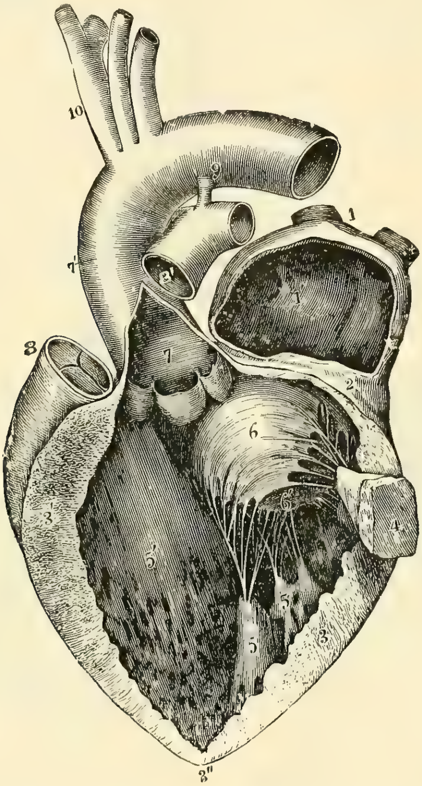

Fig. 124.—The Left Auricle and Ventricle Opened and a Part of Their Anterior and Left Walls Removed. ½.—The pulmonary artery has been divided at its commencement; the opening into the left ventricle is carried a short distance into the aorta between two of the segments of the semilunar valves; and the left part of the auricle with its appendix has been removed. The right auricle is out of view. 1. The two right pulmonary veins cut short; their openings are seen within the auricle. 1'. Placed within the cavity of the auricle on the left side of the septum and on the part which forms the remains of the valve of the foramen ovale, of which the crescentic fold is seen toward the left hand of 1'. 2. A narrow portion of the wall of the auricle and ventricle preserved round the auriculo-ventricular orifice. 3, 3'. The cut surface of the walls of the ventricle, seen to become very much thinner toward 3'', at the apex. 4. A small part of the anterior wall of the left ventricle which has been preserved with the principal anterior columna carnea or musculus papillaris attached to it. 5, 5. Musculi papillares. 5'. The left side of the septum, between the two ventricles, within the cavity of the left ventricle. 6, 6'. The mitral valve. 7. Placed in the interior of the aorta, near its commencement and above the three segments of its semilunar valve which are hanging loosely together. 7'. The exterior of the great aortic sinus. 8. The root of the pulmonary artery and its semilunar valves. 8'. The separated portion of the pulmonary artery remaining attached to the aorta by 9, the cord of the ductus arteriosus. 10. The arteries rising from the summit of the aortic arch.—(*Allen Thomson.*)

closely adherent to the muscle-tissue, termed the endocardium. It also contains elastic fibers and smooth muscle-fibers. Its entire surface is covered with a layer of polygonal endothelial cells. This membrane partially serves to resist undue distention of the heart during contraction and to prevent separation of the muscle-fibers. The endocardium is continuous with the lining membrane of the blood-vessels.

The inter-auricular septum is quite thin and composed of the two layers of the endocardium between which is a layer of muscle-fibers. It presents at its lower portion an oval depression, the *fossa ovalis.*

The inter-ventricular septum is quite thick and well developed, and composed of the two layers of the endocardium enclosing the muscle-fibers. In the upper and central portion of the septum, there is, however, a small region which is thin owing to the absence of muscle-tissue and composed of endocardium only. This region is known as the *pars membranacea septi.*

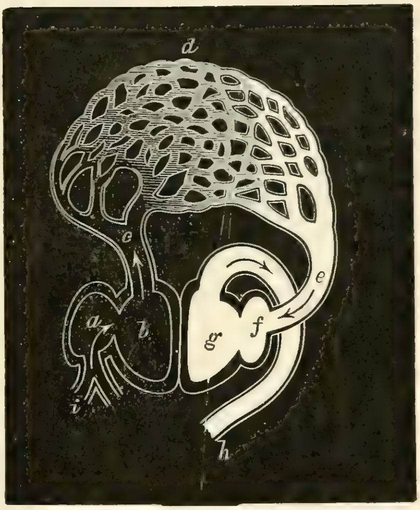

FIG. 125.—DIAGRAM OF THE CARDIO-PULMONARY VESSELS. *a.* Right auricle. *b.* Right ventricle. *c.* Pulmonary artery. *d.* Lungs. *e.* Pulmonary vein. *f.* Left auricle. *g.* Left ventricle. *h.* Aorta. *i.* Vena cava. —(*Dalton.*)

The Cardio-pulmonary Vessels.—Though the two sides of the heart are separated from each other by the auriculo-ventricular septum, they are anatomically and physiologically connected by the intermediation of the pulmonary system of vessels: viz., the pulmonary artery, capillaries, and veins (Fig. 125).

The *pulmonary artery* arises from the conus arteriosus of the right ventricle. After a short upward course it divides into a right and a left branch, which enter corresponding lungs. The vessel at once divides and subdivides into a number of branches, which, after following the bronchial tubes to their termination, give origin to capillaries that surround the air-cells of the pulmonary lobules.

The *capillaries* in this situation are extremely abundant and well developed. They lie close to the inner surfaces of the air-cells. The blood is thus brought into intimate relationship with the intra-pulmonary air, and the exchange of gases—the excretion of carbon dioxid and the absorption of oxygen—for which the cardio-pulmonary vessels exist, is readily accomplished.

The *pulmonary veins* which return the blood to the heart are formed by the convergence and union of the small veins which emerge from the capillary system. The final trunks thus formed, the four pulmonary veins—two from each lung—enter the posterior wall of the left auricle.

The Course of the Blood through the Heart.—There is thus established a pathway between the venæ cavæ on the right side and the aorta on the left side, by way of the right side of the heart, the cardiopulmonary vessels, and the left side of the heart.

The venous blood flowing toward the heart is emptied by the superior and inferior venæ cavæ into the right auricle, from which it passes through the auriculo-ventricular opening into the right ventricle (Fig. 126); thence into and through the pulmonary artery and its branches to the pulmonary capillaries, where it is arterialized by the exchange of gases—the giving up of a portion of carbon dioxid to the lungs and the absorption of oxygen—and changed in color from bluish-red to scarlet-red. The arterialized blood, flowing toward the heart, is emptied by the pulmonary veins into the left auricle, from which it passes through the auriculo-ventricular opening into the left ventricle; thence into the aorta and its branches to the systemic capillaries, where it is de-arterialized by a second but opposite exchange of gases—the giving up of a portion of its oxygen to the tissues and the absorption of carbon dioxid from the tissues—and changed in color from scarlet to bluish-red. The venous blood is again returned by the systemic veins to the venæ cavæ. Though the blood is thus described as flowing first through the right side and then through the left side, it must be kept in mind that the two sides fill synchronously; that while the blood is flowing into the right side from the venæ cavæ, it is also flowing from the pulmonary veins into the left side in equal quantities and velocities.

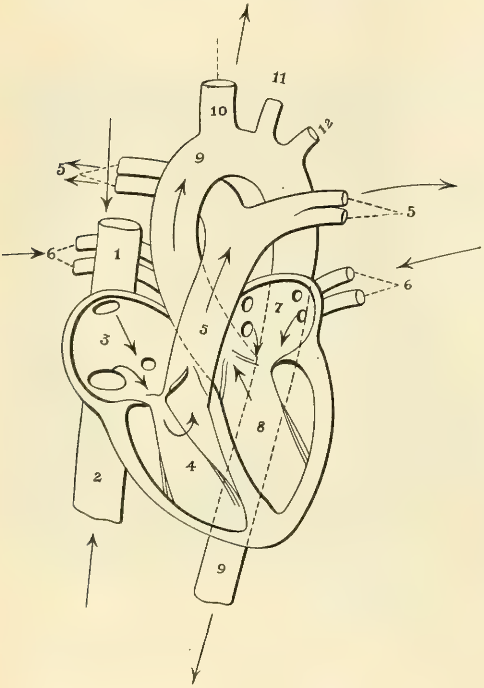

Fig. 126.—Diagram of Course of Blood through the Heart. 1, 2. Superior and inferior venæ cavæ. 3. Right auricle. 4. Right ventricle. 5, 5, 5. Pulmonary artery and branches. 6, 6. Pulmonary veins. 7. Left auricle. 8. Left ventricle. 9. Aorta. 10. Innominate artery. 11. Left carotid artery. 12. Left subclavian artery.—(*After Morat and Doyon.*)

Though there is but one set of capillaries, as a rule, between arteries and veins, there is an exception in the case of the arteries and veins of some of the abdominal viscera. Thus the veins emerging from the capillaries of the stomach, intestines, pancreas, and spleen, instead of passing directly to the inferior vena cava, unite to form a large vein—the portal vein—which enters the liver. In this organ the portal vein divides to form a second capillary system which is in close relation to the liver cells and from which arise the veins which unite to form the hepatic veins. These latter vessels empty and discharge the blood into the inferior vena cava just below the diaphragm.

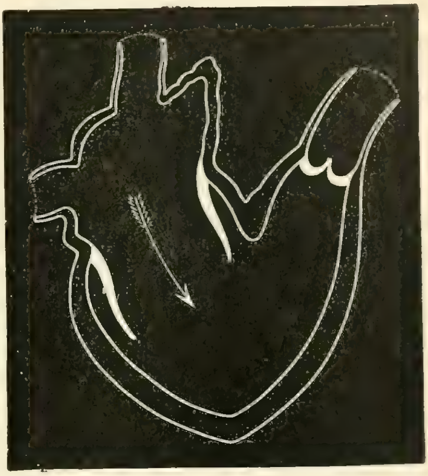

FIG. 127.—RIGHT CAVITIES OF THE HEART. Auriculo-ventricular valves open, arterial valves closed.—(*Dalton.*)

From the foregoing facts physiologists frequently divide the general circulation into:

1. The *pulmonary circulation*, which includes the course of the blood from the right side of the heart through the lungs, to the left side of the heart.
2. The *systemic circulation*, which includes the course of the blood from the left side of the heart through the aorta and its branches, through the capillaries and veins to the right side of the heart.
3. The *portal circulation*, which includes the course of the blood from the capillaries of the stomach, intestines, pancreas, and spleen through the portal vein to the liver.

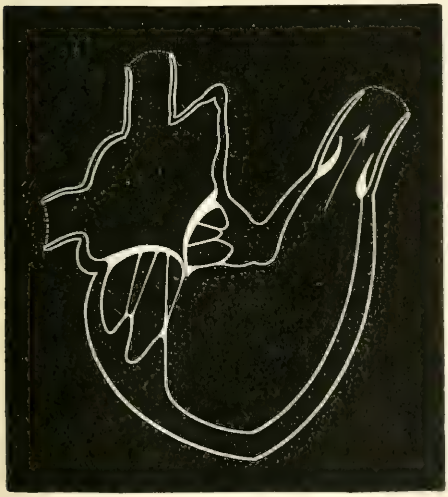

FIG. 128.—RIGHT CAVITIES OF THE HEART. Auriculo-ventricular valves closed, semilunar valves open.—(*Dalton.*)

Orifices and Valves.—The movement of the blood along the path of the circle above outlined is accomplished by the alternate *contraction* and *relaxation* of the muscle walls of the heart. That the movement may be a progressive one, that there shall be no regurgitation during either the contraction or the relaxation, it is essential that some of the orifices of the heart be closed during each of these periods. This is accomplished by the heart valves.

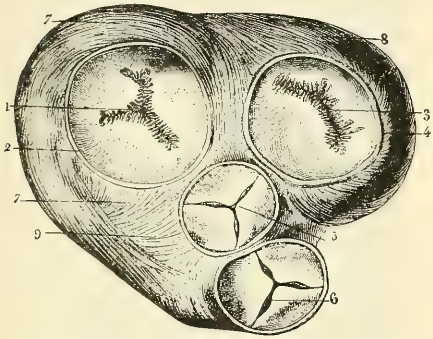

FIG. 129.—VALVES OF THE HEART. 1. Right auriculo-ventricular orifice, closed by the tricuspid valve. 2. Fibrinous ring. 3. Left auriculo-ventricular orifice, closed by the mitral valve. 4. Fibrinous ring. 5. Aortic orifice and valves. 6. Pulmonic orifice and valves. 7, 8, 9. Muscular fibers.—(*Bonamy and Beau.*)

The right auriculo-ventricular opening is surrounded and strengthened by a ring of fibrous tissue to which is attached a membrane partially subdivided into three portions or cusps, which during the period of relaxation are directed into the ventricle (Fig. 127); during the period of contraction they are raised and placed in complete apposition, when they act as a valve preventing a backward flow into the auricle (Fig. 128). In the former position the valve is open; in the latter, shut. For these reasons this structure is known as the *tricuspid valve*. This valve is formed of fibrous tissue derived from the fibrous ring, some muscle-fibers, covered over by a reduplication of the endocardium. To the under surface and to the edges of this valve the tendinous cords of the papillary muscles are firmly and intricately attached. These cords are just sufficiently long to permit closure of the valve and to prevent their being floated into the auricle.

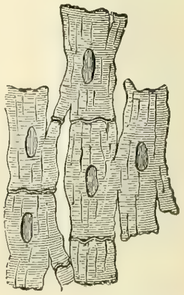

FIG. 130. — MUSCLE-FIBERS FROM THE HEART OF A MAMMAL.—(*Landois and Stirling.*)

The orifice of the pulmonary artery is also surrounded by a ring of fibrous tissue to which are attached three semilunar or pocket-shaped membranes, the semilunar valves. Each valve is formed by a reduplication of the endocardium strengthened by fibrous tissue. In the center of the free edge of the valve there is a small nodule of fibro-cartilage (the corpus Aurantius). The outer edge of the valve is strengthened by a delicate fibrous band. A similar band strengthens the convex attached portion of the valve just where it is joined to the fibrous ring. A third set of fibers pass toward the nodule, interlacing in all directions. Two narrow crescentic-shaped areas (the lunulæ) near the free edge are devoid of these fibers. During the period of *relaxation* of the heart the edges of the valves are in close apposition and prevent a return of the blood into the ventricle (Fig. 127); during the contraction they are directed into the artery (Fig. 128). In the former position they are shut; in the latter, they are open.

The left auriculo-ventricular opening is provided with a similar though better developed fibrous ring and membranous valve. It is, however, subdivided into but two portions or cusps, and is therefore termed the *bicuspid valve*, or, from its fancied resemblance to a bishop's mitre, the *mitral valve*. The general arrangement, connections, and mode of action of this valve are similar in all respects to those of the tricuspid valve. The orifice of the aorta is also surrounded by a ring of fibrous tissue to which are attached three semilunar or pocket-shaped valves (Fig. 124), which in their arrangement, connections, and mode of action are similar in all respects to those at the orifice of the pulmonary artery. The anatomic relations of the cardiac orifices one to the other and the appearance presented by the valves when closed are represented in Fig. 129.

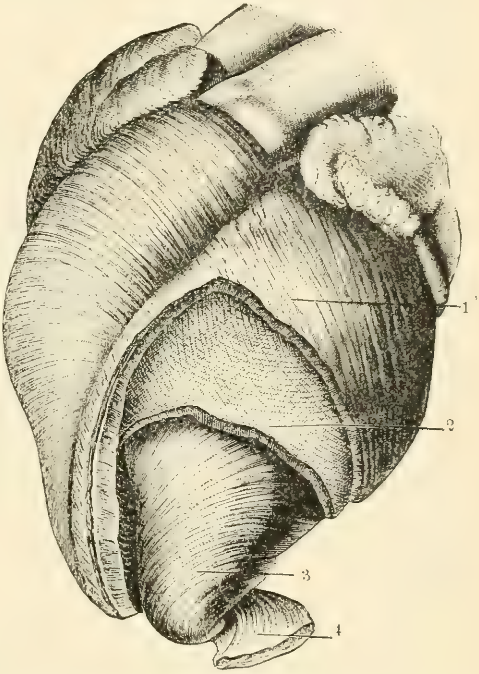

FIG. 131.—MUSCLE-FIBERS OF THE VENTRICLES. 1. Superficial fibers, common to both ventricles. 2. Fibers of the left ventricle. 3. Deep fibers, passing upward toward the base of the heart. 4. Fibers penetrating the left ventricle.—(*Sappey, after Bonamy and Beau.*)

The Heart Muscle-fibers and Their Arrangement.—The muscle-fibers of the heart, though transversely striated and nucleated, differ in shape and arrangement from those found in any other situation. The individual fiber is short and broad and usually divided at one or both ends. By this means the fibers are united not only longitudinally, but laterally. (See Fig. 130.) The fibers are devoid of a sarcolemma and united one to the other by a cement material. The entire musculature is permeated and supported by connective tissue which is so arranged as to group the fibers in bundles or fasciculi of varying size.

The arrangement of the muscle-bundles is quite complicated and in accordance with the functions of the individual portions of the heart. In the auricles the bundles are arranged in two sets: an outer transverse set, which pass from auricle to auricle, and an inner longitudinal set, which pass over the auricles and are attached anteriorly and posteriorly to the connective tissue of the transverse auriculo-ventricular septum. The longitudinal fibers of each auricle are practically independent of each other. Circularly arranged fibers are present near the terminations of the venæ cavæ and pulmonary veins.

In the ventricles the muscle-bundles are also arranged in two sets, a superficial longitudinal and a deep transverse, though their arrangement is somewhat more complicated than that observed in the auricles. In a general way it may be said that the superficial longitudinal fibers on both the anterior and posterior surfaces take their origin in the connective tissue of the auriculo-ventricular septum. The superficial fibers on the anterior surface of the heart pass obliquely downward and forward from right to left toward the apex, where they turn backward and inward in a vortex manner after which they ascend to terminate in the wall of the septum, the columnæ carneæ and musculi papillares. The superficial fibers of the posterior surface of the heart pass obliquely downward from left to right, wind around the apex, turn upward and end in the same structures as do the fibers from the anterior surface. The fibers from the base of the right ventricle terminate in the structures of the left ventricle while those from the left ventricle terminate in the structures of the right ventricle. Longitudinal fibers are also found on the inner surface. The transverse fibers are very abundant and surround each ventricle separately though they are continuous with each other across the septum. Between the superficial longitudinal and deep transverse fibers there are several layers of fibers which possess varying degrees of obliquity. The general arrangement of the fibers is such as to ensure a complete and simultaneous discharge of blood from both auricles and ventricles (Fig. 131).

THE MUSCLE CONNECTION BETWEEN THE AURICLES AND VENTRICLES.

The Muscle Band of His, or the Auriculo-ventricular Bundle.—In the mammalian heart there is no continuity of the muscle-fibers across the auriculo-ventricular groove, uniting auricles and ventricles such as exists in the frog or turtle heart. The muscle-fibers of the auricles and ventricles are completely separated from each other by the transverse fibrous septum to which they are attached. This fact has for a long time made it difficult to understand how the contraction process which begins in the auricles (to which there will be occasion to refer in subsequent paragraphs) is conducted to the ventricles. The physiologic necessity for the existence of a muscle connection between the auricles and ventricles led to a series of investigations which have resulted in the discovery of an elaborate system of muscle-fibers by which they are united both anatomicly and physiologicly.

In 1893 Wilhelm His, Jr., discovered the existence of a band or bundle of muscle-fibers which apparently took its origin from the posterior part of the right side of the auricular septum, and from which point it passed forward just above the auriculo-ventricular septum to a point near the aortic opening, where it divided into two portions, a right and a left, of which the latter apparently ended in the basis of the aortic leaflet of the mitral valve. This bundle has been termed "the muscle band of His." In 1904 Retzer and Bräunig, working independently, corroborated the existence of this bundle and described its anatomic course more completely. The investigations of Bräunig led to the conclusion that this bundle of muscle-fibers which was constantly present in all animals examined, including man, began on the right side of the auricular wall below the fossa ovalis from which point it passed forward, and anteriorly penetrated the auriculo-ventricular septum to become connected with the musculature of the ventricular septum just below the *pars membranacea septi.* Though both these observers state that the bundle divides into a right and left limb as it enters the ventricular septum, the ultimate distribution and termination of these limbs was not clearly determined. Retzer estimated that this bundle was 18 mm. long, 2.5 mm. broad, and 1.5 mm. thick. By these investigators this bundle was termed the "auriculo-ventricular bundle."

In 1906 Tawara published the results of an extended series of investigations made on the embryonic and adult hearts of many mammals including man, which resulted in a further increase of knowledge concerning the development, anatomic course and histologic features of this bundle, and established beyond doubt that it is the pathway along which the contraction process is conducted from the auricles to the ventricles.

A brief summary of Tawara's account of this bundle is as follows: It arises near the opening of the coronary sinus where it is connected with the true auricular fibers. It then passes forward on the right side of the auricular septum between the lower edge of the fossa ovalis and the auriculo-ventricular septum; just above the insertion of the median cusp of the tricuspid valve the bundle presents a very complicated network of muscle-fibers which has been designated as a knot; from the anterior portion of the knot, a bundle of fibers turns downward and penetrates the auriculo-ventricular septum, beyond which it passes through the *pars membranacea septi* to the upper limit of the muscle portion of the ventricular septum. It then divides into two limbs or branches which descend on either side of the septum under the endocardium, the right limb lying somewhat deeper than the left. Each of these limbs is enclosed by a layer of connective tissue which isolates it from the musculature of the ventricular septum as far as the lower third of the ventricular cavities. In this region they divide into a number of bundles some of which enter the papillary muscles, while others forming tendon-like strands branch freely beneath the endocardium and spread in all directions over the entire inner surface of the ventricle and enter into histologic connection with the true cardiac muscle-fibers.

The fibers composing this system, and termed by Tawara from its supposed function the "conduction system" are histologicly different from the cardiac fibers, insofar as they are poorer in sarcoplasm and similar in their appearance to embryonic muscle-fibers. In the auricular portion of the bundle the fibers exhibit a more or less reticular arrangement; in the ventricular portion, the fibers are more regularly arranged, are richer in sarcoplasm and present a number of fibrilla near their periphery.

The ultimate termination of the system, beneath the endocardium, constitutes the so-called Purkinje fiber layer. In the sheep, calf and in other animals these fibers are abundant and readily recognized; though they are not so well developed, they are nevertheless present and extensively distributed in the human heart.

More recently the connection, in the human heart, between the distal extremities of the two limbs of the muscle bundle and the subendocardial layer of Purkinje fibers has been questioned by Fahr, who has been unable to verify Tawara's statements in this respect. His findings led him to the opinion that the terminations of the limbs merge directly without any division into the musculature of the ventricle.

THE MECHANICS OF THE HEART.

The immediate cause of the movement of the blood through the vessels is the contraction and relaxation of the muscle-walls of the heart, and more particularly of the walls of the ventricles, each of which plays alternately the part of a force-pump, and to a slight extent of a suction-pump. The motive power is furnished by the heart itself, by the transformation of potential energy, stored up during the period of rest, into kinetic energy—*i. e.*, heat and mechanic motion.

The contraction of any part of the heart is termed the *systole;* the relaxation, the *diastole*. As each side of the heart has two cavities the walls of which contract and relax in succession, it is customary to speak of an auricular systole and diastole, and a ventricular systole and diastole. As the two sides of the heart are in the same anatomic relation to each other, they contract and relax in the same periods of time.

The movements of the heart, as well as many phenomena connected with the flow of blood through its cavities, have been determined by observation of, and experiment on, the exposed heart of a mammal—*e. g.*, dog, cat, rabbit—supplemented and corrected by experiments on the heart in its normal relations. Valuable information as to the heart-beat and the influences which modify it has been obtained from experiments made on the isolated heart of the turtle, frog, and allied animals.

If the thorax of a dog, completely anesthetized, is opened and artificial respiration established, the heart will be observed in active movement inside the pericardium. If this sac is divided and turned aside, the heart will be fully exposed to view. At the normal rate of movement characteristic of the dog it will be almost impossible to determine either the succession of events or their duration. But by observing the heart under different conditions at different rates of movement and with instrumental aids physiologists have succeeded not only in analyzing the movements, but in describing their sequence and in estimating their time duration.

Thus it has been determined that the heart presents two distinct movements which alternate with each other in quick succession. One is the movement of contraction, or the systole, by which the blood contained within its cavities is ejected into the arteries—pulmonary artery and aorta; the other is the movement of relaxation, or the diastole, followed by a pause during which the cavities again fill up with the blood from the venæ cavæ and pulmonary veins.

Sequence of Events.—It has been ascertained that the contraction of the auricles and ventricles as well as their subsequent relaxations, though occurring with extreme rapidity, do not take place simultaneously but successively; that the contraction process passes over the heart in the form of a wave; that it begins, indeed, at the terminations of the great veins, then passes to and over the auricles, thence to and over the ventricles from base to apex with great rapidity, but occupying in these different regions unequal periods of time; that the relaxation immediately succeeds the contraction, in the same order, and that at the close of the ventricular relaxation there is a period during which the whole heart is in repose, passively filling with blood.

Changes in Position and Form.—In passing from the diastolic to the completed systolic condition the exposed heart undergoes changes both of position and form as the contraction rises to its maximum. This having been attained, the heart undergoes reverse changes until the original diastolic condition is regained. Thus at the time of the venticular systole the apex is tilted upward, the entire heart is twisted on its axis from left to right and forced downward by the expansion and elongation of the pulmonary artery and aorta. At the time of the diastole, the reverse movements take place.

It is probable, however, that these movements are not permitted to the same extent in the unopened chest, for the following reasons: the heart is enclosed in the pericardium, is supported posteriorly by the expanded lungs, and both posteriorly and inferiorly by the diaphragm, all of which coöperate in keeping the heart, and more particularly the right ventricle, in close contact with the chest-wall and limiting its movements. By means of needles inserted into the apex of the heart, through the chest-walls, it has been shown by their slight movement that the apex is practically a fixed point.

In the diastolic condition the shape of the heart near the base is elliptic on cross-section, the long diameter extending from side to side. In the completed systolic condition the shape of the same cross-section is that of a circle. In passing from the diastolic to the systolic condition the transverse diameter diminishes while the antero-posterior diameter increases, while the whole heart becomes somewhat more conic in shape. It is questionable if the vertical diameter perceptibly shortens. During the systole the heart hardens, increases in convexity, and is more forcibly pressed against the chest-wall. As this takes place suddenly, it gives rise to a marked vibration of the chest-wall, known as the *cardiac impulse*. This is principally observed in the space between the fourth and fifth ribs, between the left edge of the sternum and a line drawn vertically through the nipple. The cardiac impulse is synchronous with the cardiac systole.

The cardiac impulse may be recorded with an appropriate apparatus known as a *cardiograph;* the record obtained with it is known as a *cardiogram*. A cardiograph consists of a tambour covered with a thin rubber membrane provided with a button. The tambour is supported by a metallic frame which permits of an easy and accurate adjustment of the button over the seat of the cardiac impulse. A rubber tube connects the cardiographic tambour with a second tambour provided with a recording lever and thus transmits all variations in the pressure of the air in the former to the latter.

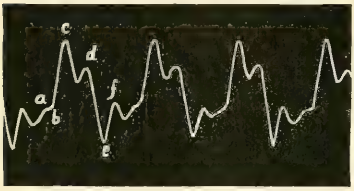

Fig. 132.—A Cardiogram.

When all adjustments are carefully made a tracing similar to that shown in Fig. 132 will be obtained in which the slight elevation *a* represents the contraction of the auricles which, completing the filling of the ventricles, causes the apex of the heart to press more vigorously against the chest wall; *b–c* represents the contraction of the ventricles at which moment the apex is suddenly and forcibly driven against the chest wall; *c–d* represents the systolic plateau, the time during which the ventricle is discharging blood into the aorta; *d–e* represents the relaxation of the ventricle while *e–f* represents the time of the diastole during which the heart cavities are enlarging with the incoming of a new volume of blood and in consequence of which the heart is pressing against the chest walls. The systolic plateau is characterized by one or more elevations and depressions, the true cause of which is unknown.

If the heart sounds are listened to at the same time the record is being taken it becomes possible to indicate by means of an electro-magnet signal the time during the beat that they occur. While it is generally admitted that the first sound is heard at *b*, there is some difference of opinion as to the time the second sound is heard. Thus while Landois places it as occurring at *d*, Edgren places it at *e*, while Marey places it at a point midway between *d* and *e*.

The Cardiac Cycle.—The entire period of the heart's pulsation may be divided into three phases, viz.:

1. The auricular contraction.
2. The ventricular contraction.
3. The pause or period of repose, during which both auricles and ventricles are at rest.

These three phases collectively constitute a cardiac cycle or a cardiac revolution. The duration of a cycle, as well as the duration of each of its three phases, varies in different animals in accordance with the number of cycles which recur in a unit of time. In human beings in adult life there are about 72 cycles to the minute; the average duration therefore is 0.83 second. From this it follows that the time occupied by any one of the three phases must be extremely short and difficult of determination. From observations made on human beings and from experiments on animals the following estimates have been made and accepted as approximately correct:

1. The auricular systole, 0.16 second.
2. The ventricular systole, 0.32 second.
3. The period of rest for both auricles and ventricles, 0.32 second.

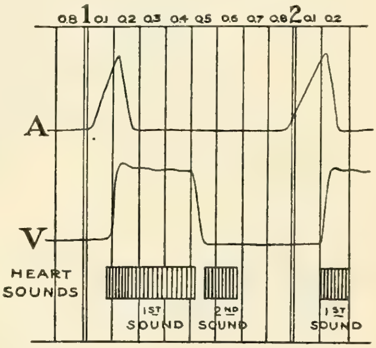

FIG. 133.—THE PHASES OF THE HEART'S PULSATION.

The relations of these three phases to one another may be illustrated by the accompanying diagram (Fig. 133), in which the space 1–2 is the duration of a cardiac cycle divided into eight equal spaces, each of which represents one-tenth of a second. The line A represents the auricular, the line V the ventricular phase. The rise in the line A represents the contraction; the fall and subsequent continuation, the relaxation and pause. The rise in the line V and its continuation represent the contraction; the fall and subsequent continuation, the relaxation and the pause. From this it is apparent that the auricular contraction or systole has a brief duration, 0.16 second, while the relaxation or diastole has a long duration, 0.64 second; that the ventricular contraction immediately following the auricular has a duration of 0.32 second, while the relaxation and diastole have a duration of 0.48 second; that the pause of the entire heart, that is, the period between the termination of the ventricular systole and the beginning of the next auricular systole, is only 0.32 second.

The frequency of the heart-beat varies with a variety of conditions: *e. g.*, age, sex, posture, exercise, etc.

Age.—The most important normal condition which modifies the activity of the heart is age. Thus:

Before birth, the number of beats a minute averages	140
During the first year it diminishes to	128
During the third year it diminishes to	95
From the eighth to the fourteenth year it averages	84
In adult life it averages	72

Sex.—The heart-beat is more rapid in females than in males. Thus while the average beat in males is 72, in females it is usually 8 or 10 beats more.

Posture.—Independent of muscle efforts the rate of the beat is influenced by posture. It has been found that when the body is changed from the lying to the sitting and to the standing position, the heart will vary as follows—from 66 to 71 to 81 on the average.

Exercise and *digestion* also temporarily increase the number of beats.

A *rise* in blood-pressure from any cause whatever is usually attended by a decrease, while a *fall* in blood-pressure is attended by an increase in the rate.

The Action of the Valves.—As previously stated, the forward movement of the blood is permitted and regurgitation prevented by the alternate action of the auriculo-ventricular and the semilunar valves. As a point of departure for a consideration of the action of the valves and their relation to the systole and diastole of the heart, the close of the ventricular systole may be conveniently selected.

At this moment, if the blood is not to be returned to the ventricles, the *semilunar valves* must be instantly and completely closed. This is accomplished in the following manner: During the outflow of blood from the ventricles the valves are pushed outward toward the walls of the vessels, though not coming into contact with them, for behind them are the pouches of Valsalva, containing blood, continuous with and under the same pressure as that in the vessels themselves. With the cessation of the outflow and the beginning of the relaxation the pressure of the blood behind the valves suddenly forces them inward until their free edges, including the lunulæ, come into complete apposition. By this means the orifices of the pulmonary artery and aorta are securely closed and a return flow prevented. Reversal of the valves is prevented by their mode of attachment to the fibrous rings of the orifices.

During the ventricular systole the relaxed auricles have been filling with blood. With the ventricular *relaxation* this volume, or its equivalent, flows readily into the empty and easily distensible ventricles, its place being taken by an additional volume of blood flowing from the venæ cavæ and pulmonary veins. Whether the ventricles exert a suction power at the moment of their relaxation is an undecided question. A steady stream of blood into the auricles and ventricles continues throughout the entire period of rest until both cavities are filled. The tricuspid and bicuspid valves which hang down into the ventricular cavities are now floated up by currents of blood welling up behind them until they are nearly closed. The auricles now contract, forcing their contained volumes, or at least the larger portions of them, into the ventricles, which become fully distended.

With the cessation of the auricular systole the ventricular systole begins. If the blood is not to be returned to the auricles at this moment, the *tricuspid* and *mitral* valves must be suddenly and completely closed. This is readily accomplished by reason of the position of the valves, which have been floated up and placed almost in apposition by the blood itself. With the beginning of the ventricular pressure the blood is forced upward against the valves until their free edges are brought together and the orifices closed. Reversal of these valves is prevented by the contraction and shortening of the *papillary muscles,* which in consequence exert a traction on their under surfaces. The blood now confined in the ventricle between the closed auriculo-ventricular and semilunar valves is subjected to pressure from all sides. As the pressure rises proportionately to the vigor of the contraction, there comes a moment when the *intra-ventricular* pressure exceeds that in the aorta and pulmonary artery.

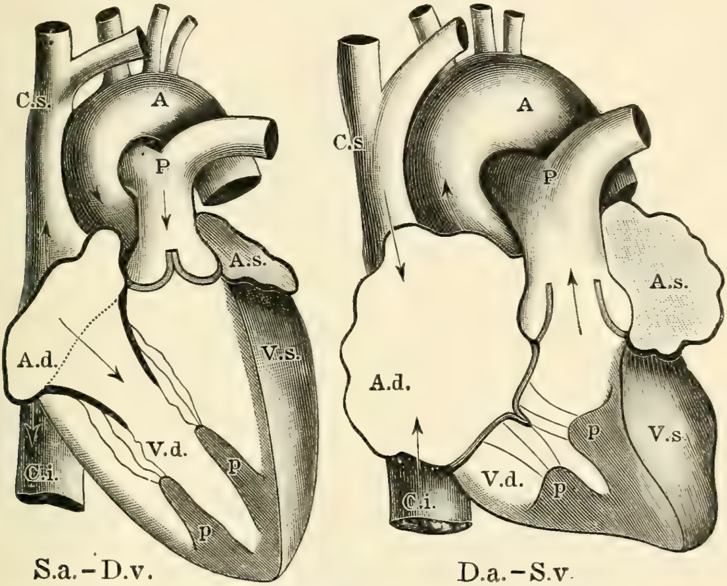

FIG. 134.—DIAGRAMMATIC REPRESENTATION OF THE AURICULAR SYSTOLE, S.a., WITH THE VENTRICULAR DIASTOLE, D.v., AND OF THE AURICULAR DIASTOLE, D.a., WITH THE VENTRICULAR SYSTOLE, S.V. C.s. and C.i. Superior and inferior cavæ; A.d. (atrium dextrum) right auricle; A.s. (atrium sinistrum) left auricle; V.d. (ventriculus dexter) right ventricle; V.s. (ventriculus sinister) left ventricle; P. pulmonary artery; A. aorta; P.P. papillary muscles.—(*Landois.*)

Immediately the semilunar valves of both vessels are thrown open and the blood discharged. Both contraction and outflow continue until the ventricles are practically empty, after which ventricular relaxation sets in, attended by a rapid fall of pressure. Under the influence of the positive pressure of the blood in the sinuses of Valsalva the semilunar valves are again closed, the column of blood supported, and regurgitation is prevented. With the accumulation of blood in the auricles the cardiac cycle is completed.

The changes in the shape of the heart, the variations in the size of its cavities and in that of the blood-vessels arising from them, the relative position of the valves during systole and diastole are shown in Fig. 134.

Relative Functions of Auricles and Ventricles.—Though both auricles and ventricles are essential to the continuous movement of blood, they possess unequal values in this respect. The passage of the blood through the pulmonary and systemic vessels is accomplished by the driving power of the right and left ventricles respectively, aided, however, by minor extra-cardiac forces. They may be regarded therefore as *force-pumps.*

If the heart consisted of ventricles only, the flow of blood from the venæ cavæ and pulmonary veins would be temporarily arrested during their systole and their subsequent refilling delayed. This is obviated, however, by the addition of the auricles; for during the ventricular systole the blood continues to flow into the auricles, in which it is temporarily stored until the ventricular relaxation sets in. With this event the accumulated blood passes into the ventricles, which are thus practically filled before the auricular systole occurs by which the filling is completed. By this means there is no delay in the filling of the ventricles, and hence their effective working as force-pumps is more readily secured. The auricles may therefore be regarded as *feed-pumps.* For this reason it is probable, notwithstanding the contraction of the circular muscle-fibers at the terminations of the venous system, the flow of blood into the auricles is never entirely arrested. Regurgitation in these vessels does not occur for the reason that the pressure in the auricles is not higher than, if as high as, in the great veins.

Synchronism of the Two Sides of the Heart.—If the balance of the circulation is to be maintained, the two sides of the heart must act synchronously. That they do so can be shown by attaching levers to their walls, and thus recording their activities. The synchronism is so perfect that until recently it was generally believed to be dependent on nerve connections; but Porter has shown that if the ventricles are cut away from the auricles, in which the nerve mechanism seemed to lie, the synchronism of the former is not interfered with; that the apical halves of the ventricles will beat synchronously if perfused with blood through an artery; that a very small bridge of muscle-tissue will carry the wave of excitation from one part to neighboring parts of the ventricle. It is therefore probable that the synchronism is accomplished through muscle connections only. The left ventricle, in keeping with the greater work it has to do, has a greater development than the right, and therefore contracts more energetically. The ratio between the energy of the left and right sides is approximately 3 to 1.

Intra-cardiac Pressure.—It has been stated that during the pause of the heart when its cavities are filling with blood the semilunar valves are kept closed by the pressure of the blood in the pulmonary artery and aorta, a pressure due to the resistance, as will be explained later, offered to the flow of the blood mainly by the smaller arteries and capillaries; that they are opened only when the pressure of the blood within the ventricle exceeds that in the arteries. It becomes, therefore, a matter of importance to determine the extent of this pressure as well as its variations during the course of a cardiac cycle. This can be done by inserting a long catheter into either the right or left ventricle, through the jugular vein or the carotid artery respectively, and connecting its free extremity with a mercurial manometer. By the interposition of a double valve such as represented in Fig. 135, it becomes possible, according to the direction the blood is permitted to flow, to obtain either the maximal or the minimal pressure that occurs in the heart during a series of cycles. Thus Goltz found in the left ventricle of the dog a maximal pressure of 114 to 135 mm.; in the right ventricle, a pressure of 35 to 62 mm. Minimal pressures of —23 to —52 mm. for the left ventricle have also been obtained.

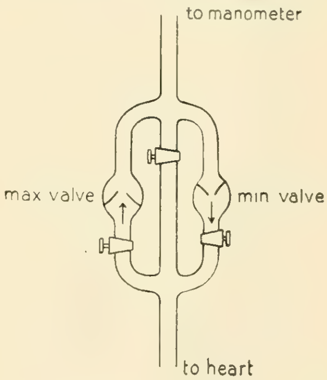

FIG. 135.—V. FRANK'S VALVE. This is placed in the course of the tube between heart and manometer, so that the latter may be used as a maximum, minimum, or ordinary manometer according to the tap which is left open.—(*Starling*.)

The maximal pressure in the ventricles during the systole, though always higher than that in the arteries, is not a fixed or an invariable pressure, as it rises and falls with the latter from moment to moment. Within limits the cardiac power, and therefore the intra-cardiac pressure, is capable of considerable increase. The function of the heart is to drive the blood through the vessels with a given velocity. This is only possible by first overcoming the resistance to the flow offered by the vessels, as indicated by the arterial pressure. As this is a variable factor, rising and falling very considerably at times, the heart must meet and exceed each rise, if the circulation is to be maintained. The power put forth by the heart is proportional to the work it has to perform. If the arterial pressure continues higher than the average for any length of time, the heart meets the condition by an hypertrophy of its walls.

The Intra-ventricular Pressure Curve.—An accurate interpretation of the play of the heart mechanism necessitates the obtaining of a graphic record of the course of the intra-ventricular pressure, its variations and time relations. With such a record may be compared the records of the pressures in the venæ cavæ, on the one hand, and in the aorta, on the other hand, and their relations one to another accurately defined.

The intra-ventricular pressure has been obtained by specially devised manometers or *tonometers* or *tonographs*, as they are variously termed, the construction of which is such as to enable them to respond instantly to the very rapid variations of the pressure which occur during the brief cardiac cycle. One of the best is that of Hürthle. This consists of a small metallic tambour 5 or 6 millimeters in diameter, covered by a thin rubber membrane. A small button resting on the membrane plays against an elastic steel spring, by the tension of which the pressure of the blood is counterbalanced. The movements of the membrane are taken up, magnified, and recorded by a suitable lever. A long cannula is inserted into the right ventricle through the jugular vein or into the left ventricle through the carotid artery. Both cannula and tambour are filled with an alkaline solution to prevent coagulation of the blood, and then joined air-tight. The pressure of the blood in the ventricle is thus transmitted by a liquid column to the tambour and to its attached lever. With such a manometer a curve is registered similar to that shown in Fig. 136. To obtain the absolute value of this curve in millimeters of mercury it is necessary to previously graduate the instrument. An examination of the curve shows that previous to the ventricular contraction there is a very slight rise of pressure above that of the atmosphere, represented by the line $a - b$. This may be due to the inflow of blood from the auricle during the diastole. At 0 the pressure suddenly rises, passes quickly to its maximum value, (2), which is maintained with slight variations for some time, and then suddenly (3) begins to fall, and rapidly reaches the line of atmospheric pressure, or even passes below it, becoming negative in fact for a short period. The curve may also be taken as a record of the ventricular contraction, for there are reasons to believe that the two closely coincide throughout their entire course. A characteristic feature of this curve is the

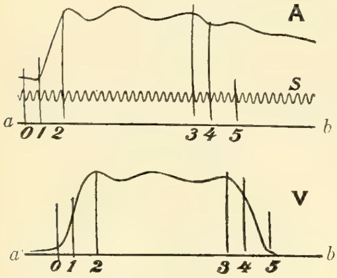

FIG. 136.—V. Curve of the pressure in the ventricle of the dog.—(*Hürthle.*) A. Curve of the pressure in the aorta. The curves were taken simultaneously. *s.* Tuning-fork vibrations, 100 per second.

more or less horizontal portion comprised between the points 2 and 3, marked by several elevations and depressions, which has been termed the systolic plateau.

With other forms of elastic manometers, especially those in which the transmission of the intra-ventricular pressure is effected by air or by a combination of air and liquid, this portion of the curve is represented by a single peak, which is taken as an indication that the maximum pressure once reached is not maintained, but immediately begins to fall to its original level, notwithstanding the continued contraction of the ventricle. Those who adhere to this view attribute the plateau to the closure of the orifice of the catheter by the contracting and approximating walls of the ventricle. There are reasons for believing, however, that the former curve is the more correct representation of the course of the intra-ventricular pressure. Bayliss and Starling photographed on a moving surface the oscillations of a fluid, a solution of sodium sulphate, in a capillary glass tube one end of which was closed, the other end placed in connection with an intra-cardiac catheter, the oscillations representing the variations in pressure. The photogram thus obtained resembles the curve obtained by Hürthle's membrane manometer.

The Relation of the Intra-ventricular Pressure Curve to the Intra-cardiac Mechanisms.—By itself the curve of the intra-ventricular pressure affords no indication as to events occurring within the heart: *i. e.*, as to the times during the systole, of the closure of the auricolo-ventricular valves and the opening of the semilunar valves, or the times during the diastole, of the closure of the semilunar valves and the opening of the auriculo-ventricular valves.

By registering the curve of pressure in the aorta simultaneously with the pressure in the left ventricle (Fig. 136), and by comparing these with the curve of the successive differences of pressure in these two cavities as determined by the "differential manometer," it becomes possible to mark on the ventricular pressure curve the points at which the foregoing events take place.

During the systolic plateau the blood is passing from the ventricle into the aorta. Independent of the slight elevations and depressions there is an absolute fall of pressure between the beginning and the end of the plateau. There is also a corresponding fall in the aortic pressure, corresponding to these two points. The curve of the difference of pressure shows, however, that the ventricular pressure is slightly higher than the aortic. This fall in both ventricular and aortic pressures is due to the escape of blood from the arterial into and through the capillary system. At 3, however, whether completely emptied or not, the ventricle suddenly relaxes, and its pressure soon falls below that in the aorta. As soon as this takes place the semilunar valves must close, if regurgitation into the ventricular cavity is to be prevented. A comparison of the aortic pressure curve shows a slight notch, the "dicrotic notch," just preceding a slight elevation, the "dicrotic" wave. This notch is taken as the moment when the semilunar valves close. The corresponding point on the ventricular pressure curve has been placed just where the ordinate 4 cuts the descending portion. As yet, however, the pressure is higher in the ventricle than in the auricle, and so continues until near the line of atmospheric pressure. At this point the pressure in the auricle, due to the accumulation of blood during the ventricular systole, now forces open the mitral valve and the blood flows into the ventricle. The opening of the mitral valve occurs about the point where the ordinate 5 cuts the curve.

The ventricular pressure curve affords but slight, if any, indication of the auricular systole. It apparently does not give rise to any noticeable increase in the ventricular pressure. The slight rise in the pressure curve, which just precedes the abrupt rise due to the ventricular systole, may be taken as an indication of an increasing pressure due to the inflow of blood from the auricle. As soon as the pressure in the ventricle exceeds that in the auricle the mitral valve closes. This is marked on the curve where the ordinate cuts it, at 0. Coincident with this, the ventricular systole begins, and as the blood is contained within a closed cavity the pressure abruptly rises. A comparison of the aortic curve shows that for a short time during the ventricular systole, the pressure is falling, but at one point it turns at a sharp angle and rapidly rises. This is an indication that the semilunar valves are suddenly thrown open and the blood begins to pass into the aorta. This event occurs at a moment marked on the ventricular curve by the ordinate 1. Beyond this point the pressure continues to rise, for the aortic pressure must not only be exceeded, but a certain velocity must be imparted to the blood. Between the ordinates 1 and 4, the semilunar valves remain open and the blood passes into the aorta.

In accordance with the foregoing

The ventricular systole may be subdivided into two periods:

1. The period of rising tension, from the beginning of the systole to the opening of the semilunar valves, occupying from 0.02 to 0.04 second.
2. The period of ejection, from the opening of the semilunar valves to the end of the systole, occupying about 0.2 second.

The ventricular diastole may also be divided into two periods:

1. The period of falling tension or relaxation, from the end of the systole to the time of lowest pressure in the ventricle, occupying about 0.05 second.
2. The period of filling, from the opening of the mitral valve to the beginning of the systole.

Negative Pressure.—As shown by the ventricular pressure curve there is a moment when the pressure falls below atmospheric pressure, becoming negative to it. The extent to which this takes place, its duration and frequency, have never been satisfactorily determined.

The cause of the negative pressure, its influence on the opening of the auriculo-ventricular valves, and on the entrance of blood into the ventricles are equally unknown. The most probable cause is an expansion of the base of the ventricles due to the enlargement of the aorta and pulmonary artery. That it is not due to the expansion of the thorax is evident from the fact that it occurs when the thorax is open and the heart exposed.

Heart-sounds.—Two sounds accompany each pulsation of the heart, both of which may be heard by applying the ear or the stethoscope to the chest-walls, especially over the region of the heart. One of these sounds is low in pitch, dull and prolonged; the other is high in pitch, clear and short. These sounds can be approximately reproduced by pronouncing the syllables lubb-dupp, lubb-dupp. The long dull sound occurs with the systole, the first phase of a new cardiac cycle, and is therefore termed the *first sound;* the short clear sound occurs at the beginning of the diastole, with the second phase of the cardiac cycle, and is therefore termed the *second sound.* The first sound is the systolic, the second the diastolic, sound. With the ear it can readily be determined that there is a brief pause between the first and second sounds, and a longer pause between the second and the first sounds. The duration of the first sound is almost equal to the duration of the systole—viz., 0.3 second; the duration of the second sound is not more than 0.1 second. The systolic sound is heard most distinctly over the body of the heart; the diastolic sound is heard most distinctly in the neighborhood of the third rib to the right of the sternum.

The *causes* of the heart-sounds have enlisted the attention of clinicians and physiologists for years, and many factors have been assigned for their production. At present it is generally believed that the *first sound* is the product of at least two, possibly three, factors: viz., the contraction of the muscular walls of the ventricles, the simultaneous closure and subsequent vibration of the tricuspid and mitral valves, and the sudden increase of pressure of the apex of the heart against the chest-wall.

That the contraction of the ventricular muscle gives rise to a sound is certain from the fact that it is perceptible in an excised heart when the cavities are free from blood and when the valves are prevented from closing. The explanation of this sound is extremely difficult, as the contraction, though prolonged, is not of the nature of a tetanus and therefore not characterized by rapid variations of tension. The apex element may be eliminated by placing the individual in the recumbent position.

The *second sound* is the product of the simultaneous closure and subsequent vibration of the aortic and pulmonary valves which occurs at the beginning of the ventricular diastole as the blood surges back against the closed valves. This has been definitely proved by the fact that the sound disappears when the valves are destroyed or held back by hooks introduced into the aorta and pulmonary artery. It is also possible that the vibration of the column of blood produces an additional tone which adds itself to that produced by the valves.

The relation of the sounds to the systole and diastole of the heart is represented in Figs. 133 and 137.

The Blood-supply to the Heart.—The nutrition of the heart, its contractility, the force and frequency of the beat, are dependent on and maintained by the introduction of arterialized blood into and the removal of waste products from its tissue. This is accomplished by the coronary arteries, on the one hand, and the coronary veins, on the other. The arteries, two in number, the right and left, arise from the aorta in the pouches of Valsalva just above the right and left semilunar valves. Turning in opposite directions, they ultimately anastomose, forming a circle around the base of the ventricles. From both the right and left artery branches are given off which run over the walls of both auricles and ventricles, the most important of which in man are the anterior and posterior inter-ventricular. These main vessels lie in grooves on the surface of the heart beneath the visceral pericardium, surrounded by connective tissue and fat. Small branches penetrate the heart-muscle in which they divide into capillaries. From the capillary areas small veins arise which, passing backward, converge to form the coronary veins. These follow the course of the arteries and finally terminate in the coronary sinus, located in the auriculo-ventricular groove on the posterior surface of the heart. This sinus opens into the right auricle between the opening of the inferior vena cava and the auriculo-ventricular opening. Its orifice is guarded by a valve, which is usually single, though sometimes double.

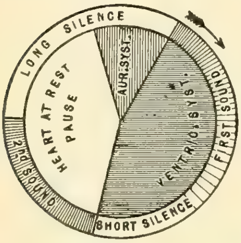

FIG. 137.—SCHEME OF A CARDIAC CYCLE. The inner circle shows what events occur in the heart, and the outer, the relation of the sounds and silences to these events.

While by far the larger portion of the blood is returned by the coronary veins, it is also certain that some of it is returned by small veins which open into little pits or depressions on the inner surface of the heart-walls, known as the foramina Thebesii. It has, however, been shown by Pratt that these foramina are present not only in the auricular wall, as generally stated, but in the walls of all the cavities. These foramina communicate through a capillary plexus with both arteries and veins, and by special large passages with the veins alone.

The period of time in the cardiac cycle during which the coronary (the extra-mural) arteries are filled with blood, whether during the systole or the diastole, has been a subject of much discussion. At present, however, as the result of many experiments it is generally believed that they are filled at the time of the systole. A comparison of the tracings of the pulse-wave taken simultaneously in the carotid and coronary arteries shows that the pressure rises and falls simultaneously in both vessels; that there is a complete agreement between the two tracings, and as a corollary both vessels are filled during the systole. But because of the pressure which the heart-muscle must exert upon the smaller arteries and veins within its own substance during systole, it is probable that there is a freer circulation in the coronary (the extra-mural) vessels, during the period of diastolic repose.

During the systole the intra-mural vessels are compressed and the blood driven out of the capillaries into the veins; during the diastole, these vessels again dilate and permit the blood to re-enter freely from the extra-mural arteries. The greater the force and frequency of the beat, the greater the volume of blood passing through the coronary system.

As stated in a foregoing paragraph the nutrition of the heart-muscle, its irritability and contractility, depend on the blood-supply derived from the coronary vessels. This is shown by the effects which follow its withdrawal. Ligation of both coronary arteries in the dog is followed by a diminution in the force and frequency of the heart-beat, and in a few minutes by complete cessation. Ligation of even a single branch of a coronary artery of the dog heart provided it supply a sufficiently large territory—*e. g.*, the arteria circumflexa—is sufficient to cause arrest in at least 80 per cent. of animals (Porter). With the ligation of this vessel there occurs a gradual diminution in the force and frequency of the systole. As the power of coördinate contraction ceases the heart-muscle frequently exhibits a series of independent contraction of individual fibers and cells known as fibrillary contraction. All the results which follow ligation are to be attributed in the light of experiment to the sudden anemia which is thus established. The removal of the ligature and the return of the blood will restore the nutrition and re-establish coördinate contractions. The excised heart of the mammal which has passed into the condition of fibrillary contraction may be again made to beat rhythmically and vigorously, by first cooling it with normal saline, and then perfusing it with warm defibrinated blood through the coronary vessels under a suitable pressure. The same result can be brought about by first perfusing it with a 1 per cent. solution of potassium chlorid until the heart comes to rest and then perfusing it with Ringer's solution.

In frogs and allied animals the heart is nourished by blood flowing, during the diastole, from the interior of the heart into a system of irregular channels which penetrate the walls in all directions. With the systole the blood is returned to the cavities. The excised heart of the mammal—*e. g.*, the cat—may be partially nourished in a similar manner through the foramina Thebesii. If the warm defibrinated blood of the same animal be introduced into the ventricle under a pressure of about 75 mm. of blood, the heart will recommence and continue to beat for a period varying from one to several hours.

The Beat of the Excised Heart.—The beat of the heart, its frequency and regularity, its continuance from the early stages of fetal development till death, has long been an interesting subject for physiologic investigation. Though related to the functional activities of the body at large, the activity of the heart is in a sense independent of them, for it will continue for a variable length of time after they have ceased. The heart of the frog and the turtle will continue to beat under appropriate conditions for hours after separation of all its anatomic connections and removal from the body. The heart of the dog or cat will, however, beat but for a few minutes. The human heart would in all probability act in the same way. Nevertheless there are good reasons for believing that though the spontaneous beat has ceased, the irritability yet endures though perhaps in lessened degree. For if, after the heart has ceased to beat for some time, warm defibrinated and oxygenated blood be passed through the coronary vessels the beat will reappear and continue at its usual rate for some hours.

The reason for the longer continuance of the beat of the excised heart of the cold-blooded animal beyond that of the warm-blooded animal lies probably in the difference in the rate of their respective metabolisms. There is reason to believe that each cell of the heart-muscle, in common with other tissue-cells, during life stores up and holds in reserve a larger quantity of nutritive material than is necessary for its immediate needs. When separated from the general blood-supply, the cells begin to utilize this reserved material. With its consumption the irritability declines and after a variable period of time disappears. As the metabolism is far more rapid in the warm-blooded than in the cold-blooded animal, it is probable that the reserved nutritive material is utilized more quickly in the former than in the latter other conditions being equal. So long as it lasts in either class, the irritability and contractility persist.

Whatever the immediate or exciting cause of the heart contraction may be, the fundamental condition for its manifestation is the maintenance of the irritability. So long as this persists at a sufficiently high level the heart-muscle will contract in response to the appropriate stimulus.

PROPERTIES OF THE HEART-MUSCLE.

The heart-muscle is characterized by the following properties, viz., irritability, conductivity, rhythmicity, tonicity, and automaticity.

1. **Irritability.**—The heart-muscle in common with other muscles possesses irritability by virtue of which it responds by a change of form to the action of a stimulus. Whatever the stimulus, here, as elsewhere, there is a conversion of potential into kinetic energy—heat, electricity and mechanic motion. The normal physiologic stimulus has not been positively determined. In

common with other forms of muscle-tissue, the heart-muscle may be made to contract by artificial stimuli—*e. g.*, mechanic, thermic, chemic, and electric.

For the demonstration of this fact it is necessary to eliminate the action of the physiologic stimulus and to bring the heart to rest in the condition of diastole. This can be done with the frog heart, by ligating the tissues between the sinu-auricular junction, a procedure which prevents the passage of the contraction wave which originates in the sinus, over the auricles and ventricles (a fact that will be more fully alluded to later). With the heart thus prepared and while still *in situ*, the apex may be connected with a recording lever and its provoked contractions registered on a recording surface. In this condition it will respond by a contraction to any form of an adequate stimulus and especially to the induced electric current. Experiment has shown that the irritability is most marked in the neighborhood of the venæ cavæ terminations. It is least marked in the ventricles.

In its irritability, contractility, and manner of response to stimuli, the heart of the mammal corresponds in all essential respects to the heart of the frog or turtle.

The irritability of the heart-muscle depends primarily on the blood-supply and secondarily on the maintenance of a normal temperature, and so long as both conditions are maintained the muscle will respond by a contraction to any adequate stimulus, physiologic or artificial.

a. The Blood-supply.—The supply of blood to the mammalian heart is derived from the coronary arteries which, though filled during the systole, deliver the blood to the intra-mural arterioles and capillaries during the diastole. The facts relating to the blood-supply have been presented fully in a foregoing paragraph.

b. The Influence of Temperature.—For the manifestation of the irritability and contractility it is essential that the heart-muscle be kept at a sufficiently high temperature in order that the physiologic or a given artificial stimulus may provoke a maximal contraction. This is accomplished by immersing the suspended heart in a bath of Ringer's solution the temperature of which can be readily decreased or increased by appropriate means. The optimum temperature for the frog heart is about 25° C. As the temperature is lowered both rate and force decrease until at about from 4° C. to 0° C. both cease. Beyond 35° C. it also ceases to contract, because of a coagulation of the muscle substance. The mammalian heart attains its maximum activity at a temperature of 37° C. It ceases to beat at about 47° C. on the one hand and at about 17° C. on the other hand.

2. **Conductivity.**—The heart-muscle possesses conductivity. The excitation process and the subsequent contraction wave, both of which take their rise under physiologic conditions near the venæ

cavæ terminations, are conducted over the auricles, thence to the ventricles from base to apex. It is now generally believed that the propagation of both processes is accomplished by muscle-tissue alone, independently of the nerve system. The conductivity, however, is not equally well developed in every part of the heart. This is especially true of the tissue at both the sinu-auricular and the auriculo-ventricular junctions. At these points in the frog heart the contraction wave is delayed for an appreciable period, a condition attributed to the embryonic character of the muscle-tissue. In the frog's heart the excitation process begins in the sinus venosus, from which it passes to the auricles, thence to the ventricles. In Fig. 138, which is a graphic record of the heart-beat, the two elevations of the level on the up-stroke, *a* and *b*, represent the contraction of the sinus and the auricle respectively, while the two depressions, *c* and *d*, indicate the delay in the transmission of the contraction wave at the two junctions. There is here an anatomic obstacle to the conduction of the contraction wave. This may be artificially increased by compressing the heart between the auricles and ventricles with a clamp. By carefully regulating the pressure it is possible to so block the wave that three or four auricular contractions may occur before the excitation process forces the block and excites a ventricular contraction. (Fig. 139.) If the block is complete, rather than partial, the ventricle will come to rest and so remain. From the foregoing facts it is evident that the physiologic stimulus exerts its action in the sinus venosus and that the auricular and ventricular beats are in turn dependent on it.

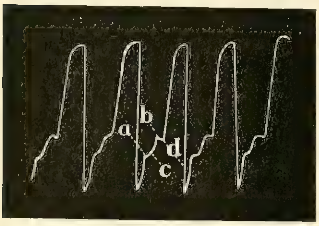

Fig. 138.—Record of the Contraction of the Frog's Heart.

In the mammalian heart the contraction wave arising at the terminations of, or at a point between the terminations of, the venæ cavæ, is likewise conducted over the auricles and thence to the ventricles; between the end of the auricular and the beginning of the ventricular contraction there is also a perceptible interval similar to that observed in the frog heart. For a long time this was attributed to an interference with the passage of the contraction wave across the auriculo-ventricular junction because of the extreme scarcity of the muscle-fibers in this region or to their embryonic character. In recent years, however, this view has been abandoned because the real bond of union between the auricular and ventricular tissues, across which the contraction wave passes, has been found, as stated on page 280, in the system of muscle-fibers, described in part by His, Retzer and Bräunig and completed by Tawara and termed by him the *conduction system of the heart.* This system it is now believed constitutes the anatomic and physiologic path across which the contraction wave passes from auricles to ventricles. The supposition that this was the case was demonstrated by Hering and others who succeeded in dividing the muscle-bundle in the excised hearts of rabbits and dogs, kept actively beating by perfusion with Ringers' solution. On division of the bundle both auricles and ventricles continued to beat though with different rates and independently of each other. These and experiments of a similar character have demonstrated beyond question that the auriculo-ventricular bundle with its widespread ramifications is the true conducting system between auricles and ventricles. The cause assigned by Tawara, for the interval between the auricular and ventricular contraction is not so much the embryonic character of the fibers of the system, as it is the length of the system as a whole, which he estimates at from 4 to 6 centimeters. Because of this fact, the excitation process requires time to pass from the beginning to the ends of the system and to all parts of the ventricles, which time is represented by the inter-systolic period or interval.

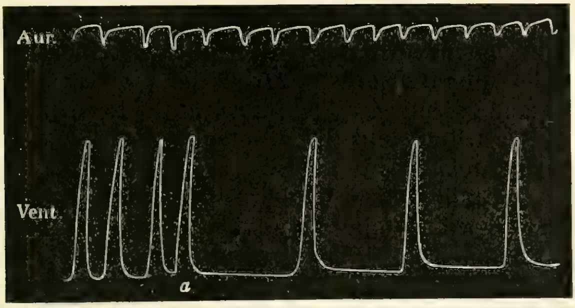

FIG. 139.—RECORD OF THE AURICULAR AND VENTRICULAR CONTRACTIONS BEFORE AND AFTER THE CLOSURE OF THE CLAMP AT *a*.

With the mammalian heart as with the frog heart it is possible to increase the length of the interval between the auricular and the ventricular contraction, the inter-systolic period, by compression of the tissues between auricles and ventricles including presumably the central part of the conducting system, the muscle band of His. This has been accomplished in the dog by Erlanger by means of a specially devised hook clamp. When the compression is brought about suddenly and completely the ventricles at once cease beating though the auricles continue to beat with their customary rate and regularity. After a variable period of time, varying from a few seconds to 70 seconds, during which the ventricles are relaxed and gradually filling with blood from the auricles, the ventricular beat returns, at first slowly but with a gradually increasing frequency until a definite but a comparatively slow rate is attained.

In experiments on the dog heart performed by Erlanger the following results were obtained when the auriculo-ventricular bundle was completely crushed.

Ven. rate per minute.	Aur. rate per minute.	$\frac{A}{V}$
Max. 69.8	216	3.7
Min. 34.8	117.8	2.4
Ave. 54.1	162.1	3.05

The reason assigned for the cessation of the ventricular contraction is the non-arrival of the excitation process at the ventricular end of the conducting system, because of the blocking or compression. Under physiologic conditions the ventricular beat is directly dependent on the arrival of the excitation process from the auricles and if it fails to arrive the ventricle does not contract for some seconds. The return of the beat during complete blocking is attributed to the development of a hitherto dormant inherent rhythmicity. When this is established both auricles and ventricles continue to beat though with a totally different rhythm.

The effects which follow gradual compression of the muscle-bundle are somewhat different from those which follow sudden compression. If the clamp is accurately adjusted and the compression gradually applied, the first perceptible effect is a lengthening of the normal pause between the auricular and the ventricular contraction. With an increase in the compression there will come a moment when one of the auricular contraction waves fails to reach the ventricle, or if it does, it is so enfeebled that it is incapable of exciting the ventricle, which in consequence fails to contract. This dropping out of a ventricular contraction may occur once in every 10, 9, 8, 7, 6, etc., auricular beats, in accordance with the degree of compression. With a further tightening of the clamp, the blocking of the excitation process may be still further increased so that only every second, third or fourth auricular beat will be followed by a ventricular beat, establishing what has been termed the 2:1, 3:1, 4:1, rhythms respectively; and finally when the blocking is complete no excitation process can reach the ventricle.

Owing to the capability of the mammalian ventricle to develop an independent rhythm when not stimulated by the auricles for a few seconds or more, it is not always possible to state at what particular moment in the successive stages of compression the independent ventricular rhythm becomes manifest. Usually when the rhythm is of the 3:1 type, *i. e.*, when the third auricular contraction fails to reach the ventricle, it will begin to beat of itself. Under such circumstances the auricles and ventricles become dissociated even though the block is not quite complete.

These experimental facts have afforded an explanation of the altered rhythm between auricles and ventricles in that pathologic condition known as Stokes-Adams disease. In this disease the rhythm may be any one of the rhythms stated in the foregoing paragraph. In two instances the following ratio of the ventricle to the auricle was observed by Erlanger.

Ven. rate per minute.	Aur. rate per minute.	$\frac{A}{V}$
22.4	79.6	3.55
31.0	84.6	2.73

In a few cases of death from this disease a postmortem examination showed a pathologic lesion of the auriculo-ventricular bundle.

3. **Rhythmicity.**—The beat of the heart is a uniform movement, occurring at regular intervals. Each phase of each beat occupies a regular measure of time. The beat is therefore rhythmic in character. The heart-muscle as a whole varies in rhythmic power in its different parts. It is best developed in the frog and tortoise, in the sinus venosus, less so in the auricles, least in the ventricles. This may be shown by division of the tissue between sinus and auricles *in situ*. At once the auriculo-ventricular portion ceases to beat, while the sinus continues contracting as usual. In a short time the auricles and ventricles begin to beat, though less rapidly than formerly. Separation of the auricle from the ventricle is again followed by rest. In due time the auricle begins to beat, while the ventricle remains quiescent. If the ventricle be now stimulated in a rhythmic manner, it may resume rhythmic activity. These facts are taken as an indication that the rhythmic power is developed in unequal degree in the three divisions of the heart.

   In the warm-blooded animal, *e. g.*, dog, cat, rabbit, there is also a difference in the rhythmicity between the auricles and ventricles. This is shown by the effects which follow division of the auriculo-ventricular bundle, or sudden and complete compression of the heart at the auriculo-ventricular groove. In either case the ventricle for a short time remains at rest, though the auricles continue to beat at their usual rate. After a variable number of seconds the ventricle develops a rhythm of its own, though it never attains that of the auricle.

4. **Tonicity.**—The heart-muscle, like the vascular muscle, maintains continuously a certain degree of contraction, termed tone, upon which the efficiency of the heart as a pumping organ is largely dependent. In the physiologic condition the ventricular muscle neither contracts nor relaxes to its fullest possible extent, but maintains an intermediate position between the two extremes and for this reason is said to possess tonicity. This tone may, however, be increased or decreased by the action of various ex-

ternal agents. Thus the passage of dilute solutions of various drugs —*e. g.*, alkalies, digitalis—through the cavities of the excised heart will so increase the tone, or the contractile power, that complete relaxation is prevented, until finally the heart comes to a standstill in the condition of systole. The passage of dilute solutions of lactic acid, muscarine, etc., through the heart will, on the contrary, so decrease the tone or the contractile power that the normal contraction is not attained. The relaxation therefore gradually increases until the heart finally comes to a standstill in the condition of diastole. In the first instance the tonicity is said to be increased; in the second instance, decreased.

5. **Automaticity.**—Inasmuch as the heart continues to contract in a perfectly rhythmic manner after removal from the body and apparently without the aid of an external stimulus, it is said that the heart-muscle is automatic or spontaneous in action. Strictly speaking, however, this is not the case, for the reason that all movement, that of the heart included, is the resultant of the action of natural causes though their true nature may be beyond the reach of present methods of investigation.

The Nature of the Stimulus.—As the heart continues to beat after removal from the body, it is evident that the stimulus does not originate in the central nerve system but in the heart itself. Two views have been held as to its origin and nature:

1. That it originates in the nerve-cells found in various parts of the heart-muscle; that it is a nerve impulse rhythmically and automatically discharged by these cells and transmitted by their axons to the heart-muscle cells.
2. That it originates in the muscle-cells themselves; that it is chemic in character and due to a reaction between the chemic constituents, organic and inorganic, of the muscle-cells and those in the lymph by which they are surrounded.

According to the first view the stimulus is *neurogenic*, according to the second view *myogenic*, in origin.

The presence of nerve-cells; their relation to the muscle-cells; the pronounced rhythmic activity of the sinus and auricles in which the nerve-cells are abundant; the feeble activity of the apex, in which they are wanting—these and other facts lend support to the view that the stimulus originates in the nerve-cells. To them have been attributed the power of automatic activity.

The absence of nerve-cells in portions of the heart-muscle, which nevertheless exhibit rhythmic contractions for quite a long period of time; the rhythmic beat of the embryonic heart before the migration of nerve-cells to its walls shows, that the stimulus does not necessarily originate in nerve-cells. Moreover, Porter has conclusively shown that the apex of the dog's heart, which is generally believed to be totally devoid of nerve-cells, can be made to beat for hours by feeding it through its nutrient artery with warm defibrinated blood. Unless it be assumed that the heart-muscle contracts automatically, without a cause, it is a fair assumption that the exciting cause of the contraction arises within the muscle-cells themselves, and that it is in all probability the outcome of a reaction between the chemic constituents and more especially the inorganic constituents of the blood or lymph on the one hand, and the chemic constituents of the muscle-cells on the other. The discovery that some of the inorganic salts of the blood have a specific physiologic action on the heart-muscle was made in 1882 by Ringer. Since then, many attempts have been made to isolate these constituents, to determine not only their individual, but also their collective action, when combined in proportions approximating those in which they exist in the blood.

The Action of Inorganic Salts.—1. *On the Frog and Terrapin Heart.*—The inorganic salts which are most directly concerned in exciting and sustaining the heart-beat are sodium chlorid, calcium phosphate or chlorid, and potassium chlorid. A combination of these salts in the proportions in which they exist in the blood was first suggested by Ringer and is made by saturating a 0.65 per cent. solution of sodium chlorid with calcium phosphate, and then adding to each 100 c.c., 2 c.c. of a 1 per cent. solution of potassium chlorid. A frog's heart immersed in this solution will continue to beat for some hours. A combination of the chlorids of sodium, calcium, and potassium in amounts which will vary for different animals is equally efficient in maintaining the heart-beat.

The collective as well as the individual actions of these salts have been strikingly brought out by the experiments of Profs. Howell and Greene, from whose published results the following statements are derived. Instead of employing the entire heart, they used for various reasons strips from the terminations of the venæ cavæ and from the ventricle of the terrapin heart. The proportion of the inorganic salts most favorable for the contraction of the vena cava strips is the following: viz., sodium chlorid, 0.7 per cent.; calcium chlorid, 0.026 per cent.; potassium chlorid, 0.03 per cent. When vena cava strips are immersed in this solution, they begin in a short time to exhibit rhythmic contractions which may continue for several days. In the same strength of solution the ventricular strips remain inactive but if the percentage of the calcium chlorid be raised from 0.026 per cent. to 0.04, or 0.05 per cent., spontaneous contractions soon develop and continue for several days or more. In the foregoing solution when the calcium chlorid is present only to the extent of 0.026 per cent., though the ventricular strip does not contract, it is kept in good condition for contraction, for even after many hours the raising of the percentage of calcium chlorid to 0.04 or 0.05 per cent. will call forth after a brief latent period, rapid and energetic contractions. From this fact it is inferred that the venæ cavæ region is more sensitive to the combined action of the salts than is the ventricle.

The action of the individual salts is also best shown with ventricular strips. In a 0.7 per cent. sodium chlorid solution the strip beats rhythmically and energetically, but for a short period and with gradually diminishing force, until it entirely ceases to beat. A reason assigned for this is the removal of other salts necessary to the excitation of the contraction. In a calcium chlorid solution—0.9 per cent.—*i. e.*, isotonic with the sodium chlorid—the heart strip is thrown into strong tone, but does not rhythmically contract. If, however, the strip is placed in normal saline, and calcium chlorid added in amounts equal to that present in the blood, it will after a very short latent period begin to contract rapidly and energetically and for a longer time than when in sodium chlorid solution alone. The contractions not infrequently occur before relaxation is completed, so that the strip passes into the condition of contracture.

In potassium chlorid solutions isotonic—0.9 per cent.—with sodium chlorid solution the heart strip also fails to contract. This is the case also when the potassium is added to the sodium chlorid in amount practically equal to that found in the blood.

2. *On the Mammalian Heart.*—The collective action of the inorganic salts on the isolated heart of all members of this class of animals, which have been made the subject of experimentation, is as marked, if not more so, than it is on the heart of the frog or terrapin especially when the coronary blood-vessels are perfused with Ringer's solution or the modification of it suggested by Locke, as follows: NaCl 0.90 per cent.; $CaCl_2$ 0.024 per cent.; KCl 0.042 per cent.; $NaHCO_3$ 0.02 per cent., dextrose 0.1 per cent. The reviving and sustaining power of this solution is extraordinary. Locke and Rosenheim were able to revive the isolated heart of a rabbit and to excite it to active contraction, for several hours at a time, on four consecutive days by perfusing it with this solution saturated with oxygen and at a temperature of 35° C. No special precautions were observed other than keeping it cool (10° C.) and moist during the intervals of experimentation. The duration of the irritability and contractility extended over a period of 95 hours. Kuliabko revived the heart of a rabbit for an hour nearly three days after removal from the body of the animal. It was then placed on ice, and after four days it was again revived by perfusing it with Ringer's solution. Altogether this heart retained its irritability for seven days. Hering revived the heart of a monkey on three different occasions, the first, 4½ hours, the second, 28 hours, and the third 54 hours after the death of the animal. In the intervening periods the heart was also kept on ice. In this animal it was even possible to increase and decrease the activity of the heart by stimulation of the nerves which normally control the rate of the beat. Kuliabko was also able to revive the isolated heart of a child 20 hours after death from a double pneumonia. It was made to beat rhythmically at a rate varying from 70 to 80 per minute when the solution had a temperature of 39° C., and at a rate of 98 to 102 per minute when it had a temperature of 41° C., though at this temperature the beat became

arrhythmic. All these instances demonstrate the extreme longevity of the irritability of the heart-muscle under appropriate conditions.

The action of individual salts has been shown experimentally on the hearts of rabbits, cats, dogs, monkeys, by Gross, Howell and others. Thus it has been found that when an isolated heart is rhythmically beating in response to the perfusion of Ringer's or Locke's solution, the addition of potassium chlorid in small amounts is followed by a decrease in the rate and force of the contraction, and in larger amounts by a complete cessation of the contraction and a standstill in diastole. On the withdrawal of the potassium, the former frequency and vigor are regained. Potassium exerts a depressor or an inhibitor influence on the irritability and contractility of the heart-muscle.

Under the same conditions, the addition of calcium chlorid in sufficient amounts is followed by an increase in the rate and in the vigor of the contractions; on its withdrawal both rate and force return to the previous condition. Calcium exerts an accelerator and an augmentor influence on the irritability and contractility of the heart.

The Cause of the Heart-beat.—From the foregoing facts it seems probable that the heart-beat is connected with and dependent on the presence and interaction of the inorganic salts present in the lymph, though as to the manner in which they interact to initiate the beat, there is some obscurity. A very plausible theory as to the part played by the inorganic salts in initiating the contraction and one in accordance with the facts has been presented by Howell as follows:

The heart-muscle, it is assumed, contains a stable organic energy-yielding compound of which potassium is one of its constituents and on which its stability depends. This compound must be present in relatively large amounts as the heart will continue to contract and expend energy for many hours after the blood-supply has been withdrawn.

During the diastole a reaction takes place between this compound and the calcium or the calcium and the sodium salts, whereby a portion of the organic compound is freed from potassium and is then combined with calcium, or with calcium and sodium. In consequence, this portion of the organic compound in combination with the calcium acquires and gradually increases in instability, reaching its maximum at the end of the diastole, when it undergoes a dissociation giving rise to a chain of events that culminate in a contraction. The initial step, therefore, is a dissociation of a complex unstable molecule followed by an oxidation of the dissociated products. That an active dissociation of some character takes place is evident from the consumption of oxygen, the production of carbon dioxid, the liberation of heat, electricity and mechanic motion.

Inasmuch as the contraction is always maximal and as the heart is refractory to a stimulus during the systole, the probabilities are that all of the energy-yielding unstable compound is dissociated with each contraction. With the relaxation there is a renewal of the unstable molecules along the lines stated above, which increase in number and instability until the maximum is again attained when another dissociation occurs followed by another contraction. The rhythmicity of the heart's action, the appearance of a refractory condition during the systole and its gradual disappearance during the diastole, as well as other phenomena, are readily explained by the foregoing hypothesis.

The cause of the dissociation of the energy-yielding material is, however, a subject of discussion. According to Howell it is not necessary to assume the presence of any cause other than the extreme instability of the organic compound in question. According to Engelman, Langendorff and others, the dissociation is not spontaneous but is the result of the action of a specific stimulus, an "inner stimulus," arising within the muscle elements themselves through metabolic processes; and so long as these processes are chemically and physically conditioned by blood or tissue fluids containing the inorganic salts, so long will this stimulus be produced. As to the nature of this stimulus, whether chemic, electric or enzymic, nothing definite can be stated at present.

The Response of the Heart to the Action of a Stimulus.—The heart of the frog as well as of some other animals may be brought to a standstill by the ligation of the tissues between the sinus venosus and the auricle, a procedure first introduced by Stannius and now known as the first Stannius ligature. Under such circumstances the heart may be made to contract by stimulating it with the single induced current. With each passage of the current the heart contracts. Contrary to what is observed in other muscles, the heart-muscle, if it contracts at all, at once reaches its maximal value. Any increase in the strength of the stimulus above the threshold value has no greater effect on the extent or force of the contraction than the minimal stimulus. A conclusion which may be drawn from this fact, according to Engelman, is as follows: By reason of the fact that the heart contracts at its maximum value to the action of any strength of stimulus, under given conditions, there is always ensured a complete emptying of the ventricular contents and a uniform discharge of blood into the arteries, which would not be the case if the extent of the contraction varied with the strength of the stimulus; and there are reasons for believing that the normal stimulus for the contraction varies within wide limits above the threshold value both in normal and abnormal conditions of the heart. The changes in the extent or force of the contraction are the result, not of changes in the intensity of the stimulus, but of changes in the heart-muscle, caused by variations in mechanical resistances.

The periodicity of the heart's action or its rhythm may also be elucidated by the foregoing fact. There are reasons for believing that at the time of the contraction practically all of the available energy-yielding material is completely utilized, after which the heart relaxes and remains at rest in the diastolic condition for a given period; and before a second excitation wave can be developed and pass from the sinus over the heart there must be a re-accumulation of energy-yielding material, and a restoration of the irritability. This is accomplished during the diastole. By virtue of this fact the heart can not act otherwise than in a periodic or rhythmic manner.

Inasmuch as there is a conversion of all of the potential energy into kinetic energy during the systole, there is of necessity, a lowering of the irritability, and to so great an extent is this the case that the heart will not respond to the action of a second stimulus either physiologic or artificial during the systolic period. This non-responsiveness of the heart may be shown by throwing into it a second stimulus at any moment during the systole. Whatever the moment or whatever the strength of the stimulus may be the extent of the contraction remains the same. During the systolic period the heart is said, therefore, to be *refractory* to a second stimulus. If, however, a second stimulus of average strength be thrown into the ventricle at any moment during the relaxation, a second contraction or extra systole will be developed. The extent of this contraction will be proportional to the time at which the stimulus is thrown into the ventricle as it passes from the beginning to the end of its relaxation. Whatever the extent of the extra contraction it superposes itself on the first, though its height is no greater than the first. For this reason it is believed a tetanic contraction can not be developed. If the stimulus be thrown into the heart just as the relaxation is completed, the extra contraction attains the same height as the preceding contraction. In passing from the beginning to the end of the relaxation and into the diastolic or resting period, it has been found that the extra contraction can be provoked by a stimulus which is steadily decreased in intensity. It is evident from this fact that the restoration of the energy-yielding material and the return of the irritability gradually increases from the beginning of the relaxation to the end of the diastole. For this reason weak stimuli are more effective in the later than in the earlier period of the relaxation and the diastole.

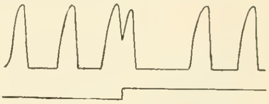

FIG. 140. — THE EXTRA CONTRACTION AND THE COMPENSATORY PAUSE. The break in the horizontal line indicates the moment the electric current passes through the heart.

After the development and disappearance of the extra contraction a considerable pause in the heart's action occurs to which the term *compensatory pause* has been given (Fig. 140), on the assumption that it was necessary on the part of the heart to compensate for the disturbance of the rhythm by remaining at rest until the time of the next beat and thus restore the rhythm. This was thought to be a special property of the heart-muscle. This view, however, is no longer entertained. For if an isolated ventricle of a frog heart be employed and made to contract rhythmically by an artificial stimulus, or if a spontaneously beating portion of the dog's heart be employed for experimentation instead of the whole heart, the results of the same methods of stimulation are different. Though an extra contraction is called forth as usual, there is no compensatory pause; indeed, if anything the pause is shorter than the regular pause. The theory of a necessary compensation is unnecessary.

The explanation assigned and generally accepted at present for the production of a compensatory pause is as follows: In a spontaneously beating heart the ventricular contraction is provoked by the arrival of an excitation process coming from the auricles. When the extra contraction is induced by an artificial stimulus, the next succeeding excitation from the auricle falls into the refractory period and hence the ventricle is not stimulated. It, therefore, simply waits for the arrival of the third succeeding excitation, when it responds and takes up the regular rhythm.

If a series of successive stimuli be thrown into the heart-muscle the effect will vary in accordance with their time intervals. Should this be less than about three seconds there will be a gradual increase in the height for some half dozen contractions, a result to which the term "staircase" or "treppe" has been given. This increase in the height of the contraction is attributed to an increase in the irritability and contractility of the muscle the result of the primary stimulating action of fatigue products.

THE NERVE MECHANISM OF THE HEART.

By this term is meant a combination of nerves and nerve-centers which coöperate to increase or decrease either the rate or force—or both—of the heart's contraction in accordance with the needs of the system. That the heart is normally influenced by the central organs of the nerve system in response to the action of nerve impulses reflected to them from many organs of the body is a matter of personal experience; that it is abnormally influenced by the same or other organs in response to nerve impulses reflected to them in consequence of pathologic and traumatic processes occurring in different regions of the body, and that both heart and nerves are modified in different ways by the action of drugs introduced into the body, are matters of daily clinical experience.

The nerves comprising this mechanism and the relation they bear one to another are represented in Fig. 141.

It was stated in a previous paragraph, page 296, that the contraction of the heart-muscle is independent of its connection with the central organs of the nerve system, and that it will continue to contract in a rhythmic manner for a variable length of time even after its removal from the body of the animal, the length of time varying with the animal and the conditions to which it is subjected; that the stimulus is myogenic in origin and chemic in character, the result of a reaction between the chemic constituents, organic and inorganic, of the muscle-cells and those in the lymph by which they are surrounded. It has also been further shown that even in the living animal the heart will continue to beat and fulfil its functions after

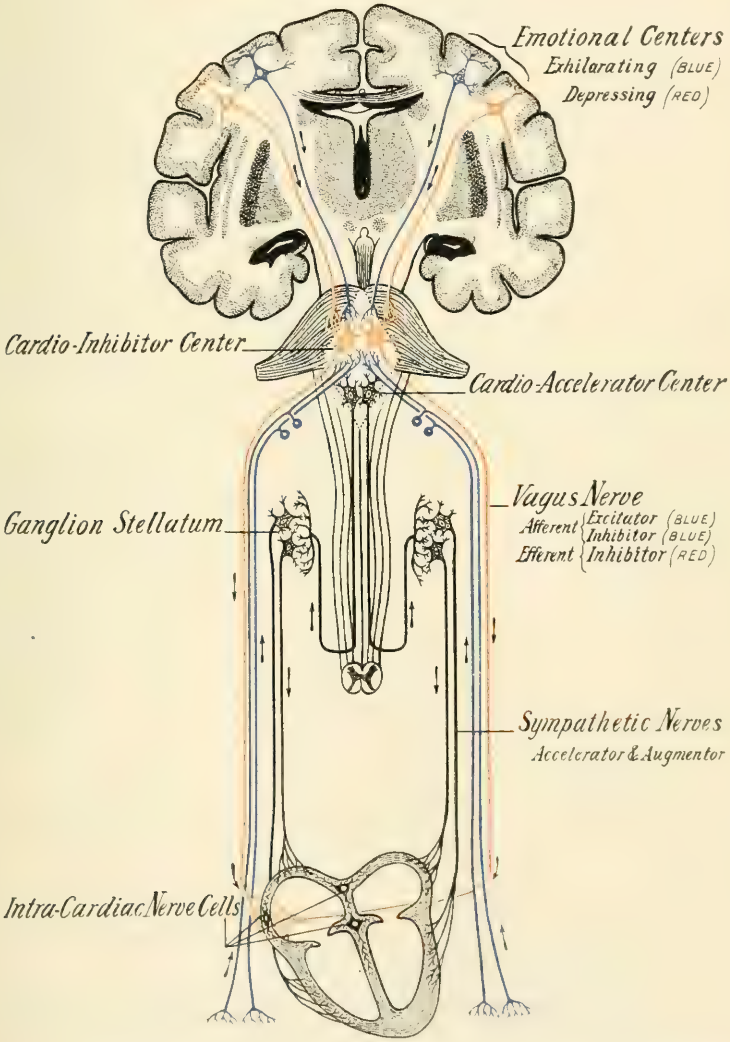
Emotional Centers
Exhilarating (BLUE)
Depressing (RED)
Cardio-Inhibitor Center
Cardio-Accelerator Center
Vagus Nerve
Afferent {Excitator (BLUE) Inhibitor (BLUE)
Efferent {Inhibitor (RED)
Ganglion Stellatum
Sympathetic Nerves
Accelerator & Augmentor
Intra-Cardiac Nerve Cells

FIG. 141.—DIAGRAM OF THE NERVE MECHANISM OF THE HEART.—(*G. Bachman.*)

division of all nerves in connection with it. A dog thus experimented on lived for eleven months, and beyond the fact of becoming fatigued more readily upon exertion than formerly, exhibited no striking disturbance of his functions. Nevertheless groups of nerve-cells are present in certain portions of the heart in all classes of vertebrate animals, which bear an anatomic and physiologic relation to the heart-cells on the one hand, and to the nerves connecting them with the central organs of the nerve system on the other hand.

Intra-cardiac Nerve-cells.—In the frog heart a group of nerve-cells is found in the sinus at its junction with the auricle, known as the crescent or ganglion of Remak; a second group is found at the base of the ventricle on its anterior aspect, and known as the ganglion of Bidder; a third group is found in the auricular septum, known as the septal ganglion, or v. Bezold's or Ludwig's. The majority of the cells are situated on the surface of the heart just beneath the pericardium. From the cell-body fine non-medullated fibers pass into the substance of the heart, to become histologically and physiologically related with the muscle-fiber.

In the dog heart and in the mammalian heart generally, though nerve-cells are present, they are not arranged in such definite groups, but are more widely distributed in the terminations of the venæ cavæ, pulmonary veins, the walls of the auricles, and in the neighborhood of the base of the ventricles.

Extra-cardiac Nerves.—The extra-cardiac nerves which connect the heart with the central nerve system and through which the activities of the heart are influenced are two: viz., the sympathetic and the vagus or pneumogastric. Experimental investigation has established the fact that the sympathetic is the motor nerve to the heart, the nerve which accelerates the rate and augments the force of the natural beat; while the vagus is the inhibitor nerve, the nerve which inhibits or controls the rate and the force of the beat in accordance with the necessities of blood distribution. For this reason these two nerves will be considered in the following order. The course of the fibers composing these nerves, from their origin to their termination, and the relation they bear to one another and to neighboring structures, vary somewhat in different animals.

The Origin and Distribution of the Sympathetic Nerves in Mammals.—The sympathetic nerve-fibers which influence the action of the heart, are connected on the one hand with the heart-muscle itself and on the other hand with nerve-fibers coming from the central nerve system. The former are non-medullated and post-ganglionic, the latter medullated and pre-ganglionic.

The pre-ganglionic fibers have their origin in the medulla oblongata and very probably from nerve-cells in the gray matter beneath the floor of the fourth ventricle. From this origin they descend the spinal cord as far as the level of the second and third thoracic nerves. At this level they emerge from the cord in company with the nerve-fibers composing the anterior roots of the second and third thoracic nerves. After a short course, they enter the white rami communicantes, enter the sympathetic chain and pass upward to the ganglion stellatum, and by way of the annulus of Vieussens to the inferior cervical ganglion as well around the nerve-cells of which their terminal branches arborize. From the nerve-cells of both the stellate and inferior cervical ganglia, the sympathetic nerves proper arise which after emerging from the ganglia pass towards the heart and become associated with the fibers of the vagus and assist in the formation of the cardiac plexuses. On reaching the heart they may terminate directly in the muscle-cell or indirectly through the intermediation of intra-cardiac nerve-cells. The former mode of termination is the more probable. Experiment has shown that both the pre- and post-ganglionic fibers are efferent in function.

The Origin and Distribution of the Vagus Nerve in Mammals.—The vagus nerve-fibers which influence the heart are connected on the one hand with the heart through the intermediation of the intra-cardiac cells, and on the other hand with the central nerve system. Histologic investigation has shown that the vagus nerve-trunk of man and mammals generally, contains medullated fibers of large and small size. Experiment has shown that the large fibers are *afferent*, the small fibers *efferent* in function.

The large afferent fibers arise in the ganglia situated on the trunk of the nerve. From their contained nerve-cells a short axon process proceeds which soon divides into a central and a peripheral branch. The central branch passes toward and into the gray matter beneath the floor of the fourth ventricle where its end-tufts arborize around nerve-cells; the peripheral branch passes toward the general periphery to be distributed to the mucous membrane of the lungs, stomach, intestine, etc. The small efferent fibers are the peripherally coursing axons of nerve-cells situated in the gray matter beneath the floor of the fourth ventricle at the tip of the calamus scriptorius. The exact course of these fibers from their origin into the trunk of the vagus is not positively known. According to some investigators, they leave the medulla by way of the spinal accessory nerve and enter the trunk of the vagus through its internal or anastomotic branch; according to recent investigations made by Schaternikoff and Friedenthal, they leave the medulla along the path by which the afferent fibers enter and never become associated with the spinal accessory nerve at its origin.

In the neighborhood of the inferior or recurrent laryngeal nerves, branches containing efferent fibers are given off, which pass to the heart by way of the cardiac plexus. The terminal branches of these fibers are not distributed directly to the heart-muscle, but to the intra-cardiac nerve-cells, around the bodies of which they end in basket-like formations. The fibers in the vagus are pre-ganglionic; those of the nerve-cells post-ganglionic. (See Fig. 142).

In the *frog* and allied animals the relation of these two sets of nerve-fibers, viz., the efferent sympathetic fibers and the efferent vagus fibers, is somewhat different; and because of the fact that these nerves in this animal are largely employed for determining experimentally their respective actions on the heart, this relation should be clearly understood.

The sympathetic nerve-fibers in this animal are also in connection with the heart on the one hand and with nerve-fibers coming from the central nerve system on the other hand. The pre-ganglionic fibers take their origin very probably in nerve-cells in the medulla oblongata. From this origin they descend and emerge from the spinal cord in the anterior roots of the third spinal nerve, then pass through the white rami communicantes to the third sympathetic ganglion around the nerve-cells of which their terminal fibers arborize.

From the nerve-cells of this ganglion, the sympathetic nerves proper, the post-ganglionic, non-medullated fibers arise. From this origin they ascend, passing successively through the second sympathetic ganglion, the annulus of Vieussens, the first sympathetic ganglion, to the ganglion on the trunk of the vagus, at which point they enter the sheath of the vagus fibers and in company with them pass to the heart. For this reason the common trunk is generally spoken of as the *vago-sympathetic* nerve.

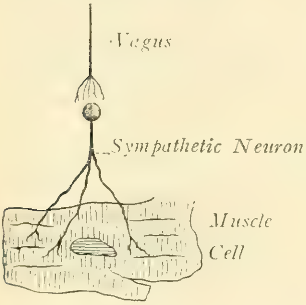

FIG. 142.—DIAGRAM SHOWING THE RELATION OF THE VAGUS TO THE HEART MUSCLE-CELL.

The vagus nerve is connected with the medulla oblongata by a series of from six to eight roots. A short distance from the medulla, the nerve trunk passes through a large opening in the cranium beyond which it presents an enlargement, termed the vagus ganglion. The peripheral end of this ganglion gives off two trunks, one the glossopharyngeal, the other the vagus proper.

The vagus nerve proper in the frog also consists of both afferent and efferent fibers which have practically the same origin, distribution and termination as the corresponding fibers in the mammal.

After the union of the sympathetic fibers with the vagus fibers, the common trunk passes forward to the angle of the jaw, winds around the pharynx just beneath the border of the petro-hyoid muscle and in close relation with the carotid artery. As the nerve approaches the heart it divides into two branches, the pulmonary and the cardiac. At the sinus venosus some of the fibers become related, histologically and physiologically, with the ganglion cells, while others plunge into the heart, course along the auricular septum on the left side and finally terminate at or near the ganglion cells of the base of the ventricle. The mode of termination of both the vagus and sympathetic fibers is similar to that observed in the mammals.

The Physiologic Actions of the Sympathetic Nerves in the Frog. The information now possessed regarding the influence which the central nerve system exerts on the heart through these nerves, has been derived largely from experiments made on the nerves of the frog, toad, and turtle. Inasmuch as the sympathetic and vagus nerves in the frog and related animals are bound up in a common sheath, it is necessary in order to demonstrate their respective functions to first divide the nerves, before their union at the vagus ganglion, and then stimulate their peripheral ends. The heart should be exposed and attached to a recording lever so that its movements may be taken up and recorded on a moving recording surface.

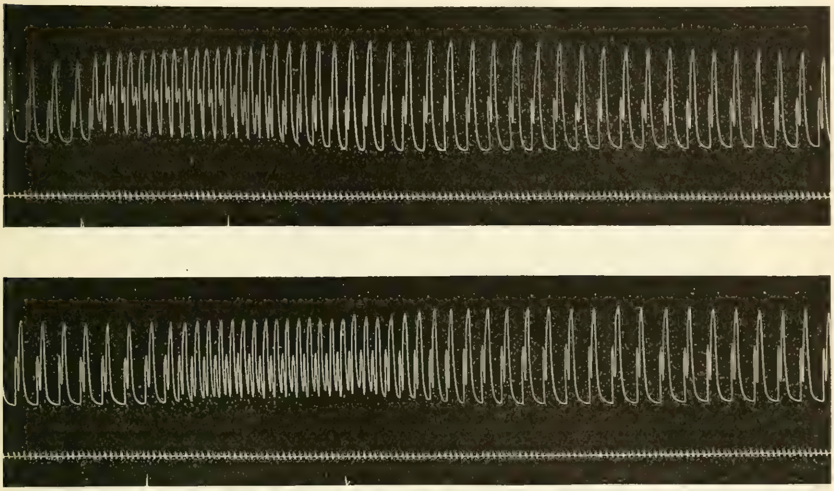

FIG. 143.—TRACINGS SHOWING THE EFFECTS ON THE HEART-BEAT OF THE FROG FROM STIMULATION OF THE SYMPATHETIC NERVES PRIOR TO THEIR UNION WITH THE VAGUS NERVE. The upper tracing shows an increase in the rate which before stimulation was 15 per minute and during stimulation 30 per minute. Before stimulation the height of the ventricular beat was 9 mm. and during the stimulation it was 12 mm. The lower tracing shows a similar series of effects, the differences being only of degree.—(*Brodie.*)

Stimulation of the sympathetic fibers with induced electric currents, prior to their union with the vagus, is followed by an increase in the rate or an augmentation in the force of the heart-beat or both at the same time. The effects of such a stimulation with induced currents of moderate intensity are graphically shown in Fig. 143. The upper tracing shows that the heart was first accelerated, the beats increasing from 15 per minute before stimulation, to 30 per minute during stimulation. On the cessation of the stimulation, the heart slowly returned to its former rate. Coincidently with this acceleration of the rate there was an augmentation of the force of the ventricular contraction as shown by an increase in the height of the ventricular contraction which before stimulation was 9 mm., but during stimulation 12 mm.

In addition to the foregoing changes in the heart-beat there is an alteration in the sequence of the beat. The natural delay in the conduction of the excitation process from the auricles to the ventricle is increased, in consequence of which the auricle completely relaxes before the ventricular contraction begins. Moreover, the auricular contraction again occurs before the ventricle has completely relaxed. After the effect of the stimulation passes away, the acceleration diminishes, the augmentation declines and a reverse change in the sequence occurs. The lower tracing shows a similar series of effects. If the stimulus be applied to the pre-ganglionic sympathetic nerves, an acceleration or augmentation of the heart follows, similar in all respects to that which follows stimulation of the post-ganglionic or sympathetic fibers proper; and the inference may be drawn that if the stimulus could be applied directly to the nerve-cells in the medulla oblongata from which the fibers take their origin, the same acceleration or augmentation would follow; for this reason this collection of nerve-cells is known as the *cardio-accelerator* or *augmentor* center. Since stimulation of the nerve in any part of its course, which in all probability exaggerates its normal function, is followed by an acceleration or an augmentation, the sympathetic is said to have an accelerator or an augmentor influence on the heart-beat; with the cessation of the stimulation, and very frequently before, the heart returns to its normal condition.

The Physiologic Action of the Vagus Nerve in the Frog.—*Stimulation* of the intra-cranial roots of the vagus with very weak induced electric currents is followed by a gradual diminution in the rate and a diminution in the force of the heart-beat. If the induced currents are moderate in strength, the heart will at once come to a standstill in diastole. (Fig. 144.) If the stimulus be applied to the trunk or the peripheral portion of the vagus, for example close to the sinu-auricular junction, an inhibition occurs similar in all respects to that which follows stimulation of the intra-cranial roots, and judging from what is known regarding the action of nerve-cells, the inference may be drawn that if the stimulus could be applied directly to the group of nerve-cells from which the efferent fibers arise, the same inhibition would follow; for this reason this collection of nerve-cells is known as the *cardio-inhibitor* center. Since stimulation of the nerve, either at its center, in its course, or at its periphery, and which in all probability exaggerates its normal function, is followed by a period of rest or inactivity, the vagus is said to have a retarding or an inhibitor influence on the beat of the heart.

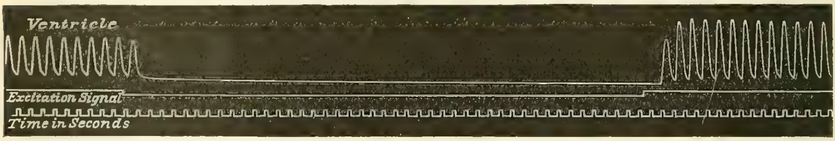

Fig. 144.—Tracing showing the Effect on the Heart-beat of the Toad of long Stimulation of the Intra-cranial Roots of the Vagus with Moderately strong Electric Currents.—(*Gaskell.*)

During the continuance of the inhibition, the heart-muscle is relaxed, its cavities dilated and filled with blood. The dilatation usually exceeds that observed prior to the vagus stimulation.

After cessation of the stimulation, the heart resumes its activity. At first the beat usually is slow and feeble, but with each succeeding beat both rate and force increase, until they attain or exceed that observed prior to the stimulation. In some cases, however, the heart begins to beat with as much and even more vigor than it did prior to the stimulation. The duration of the inhibitor effect varies with the duration of the stimulation. Thus during and after a stimulation of thirty-eight seconds the heart of the toad remained at rest for 292 seconds (Gaskell); the heart of a snake for from one-half to one hour (Meyer); the heart of a turtle for four and a half hours (Mills). The period of inhibition will depend on the strength of the electric current employed, the nerve stimulated, the season of the year, etc.

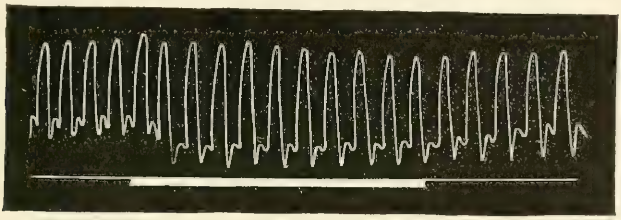

Fig. 145.—Tracing showing the Diminution in the Rate of the Heart-beat following Weak Tetanization of the Vagus Trunk.

The effects on the heart-beat which will follow stimulation of the vago-sympathetic in its course vary, however, because of the antagonistic action of the inhibitor and accelerator nerve impulses. Thus stimulation of the peripheral end of the divided *trunk* of the vagus in the frog or the toad with weak tetanizing induced electric currents is followed by an increase in the rate of the heart-beat because of the stimulation of the accelerator fibers which apparently respond before the inhibitor fibers; stimulation with somewhat stronger currents is followed by a diminution in the rate of the beat because of the greater effect on the inhibitor nerve-fibers (Fig. 145). Stimulation with strong tetanizing currents is followed by complete inhibition (Fig. 146).

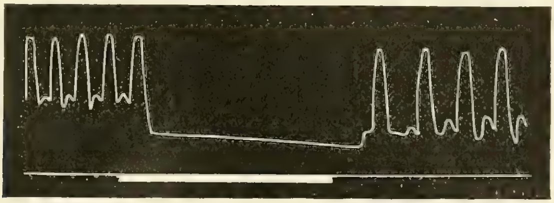

Fig. 146.—Tracing showing Complete Inhibition following Strong Tetanization of the Vagus Trunk.

The foregoing facts lead to the inference that the cardio-accelerator and the cardio-inhibitor centers have as their function the discharge of nerve impulses which are conducted by their related nerves, the efferent sympathetic and vagal fibers, to the heart, and which, in an as yet unexplained manner, accelerate or augment or inhibit, the action of the heart. The relation which these two centers bear one to the other and the manner in which they are influenced in their activities both directly and reflexly and thus regulate the action of the heart from moment to moment will be considered in a subsequent paragraph.

Changes in the Conductivity of the Heart.—In addition to the changes in the rate and force of the heart caused by stimulation of the inhibitor and the augmentor nerves, it is stated by Gaskell that there is also during the inhibition a *decrease* in the conductivity of the heart at both the sinu-auricular and auriculo-ventricular junctions, and an *increase* in the conductivity during acceleration of the beat. The decrease in conductivity may be so pronounced that only every second or third contraction of the auricle will be followed by a contraction of the ventricle. In other instances both auricles and ventricles remain at rest while the sinus maintains its usual rate. The increase in conductivity is shown by first artificially blocking the contraction wave at the auriculo-ventricular junction with the clamp, until only every second or third auricular contraction is conducted to the ventricle, and then stimulating the sympathetic. At once the auricular contraction forces the block, and passes to the ventricle, calling forth a normal contraction.

The Physiologic Actions of the Sympathetic Nerves in Mammals.—In the mammal, stimulation of the sympathetic nerves in any part of their course, either through the rami communicantes, the ventral portion of the annulus of Vieussens, or after their emergence from the stellate or inferior cervical ganglia is followed by effects similar to those observed in the frog: viz., an acceleration or augmentation, or both, of the heart-beat. The percentage increase in the acceleration varies in different animals. In some instances the increase varies from 58 per cent. to 100 per cent. (Hunt). If the heart is beating slowly before stimulation, the acceleration is more marked than if it is beating rapidly.

The effect of the accelerator impulses is apparently a change in the inner mechanism of the heart-muscle itself and not to a change in the peripheral portion of the inhibitor apparatus. This is indicated by the fact that acceleration occurs after the full physiologic action of atropin which acts upon, and impairs the conductivity of, the intracardiac nerve-cell terminals.

A peculiarity of the sympathetic nerve is that it does not respond to stimulation as rapidly as do many nerves, so that a rather long latent period intervenes between the moment of stimulation and the appearance of the acceleration as shown in Fig. 147. A further peculiarity is that the acceleration sometimes continues after the stimulus is withdrawn, and sometimes ceases before it is withdrawn.

Though an increase in both the rate and force frequently occur simultaneously, there is no necessary relation or connection between the two as they can and do occur independently of each other. For this reason it is generally assumed that the sympathetic nerves contain two groups of fibers, viz., accelerators and augmentors, the functions of which are to respectively accelerate the rate and augment the force of the heart-beat. From the fact that both auricles and ventricles exhibit these changes it is assumed that the nerve impulses stimulate both chambers. This is rendered probable also from the experiments of Erlanger, who found that after complete heart block, stimulation of the sympathetic caused independent acceleration of both auricles and ventricles.

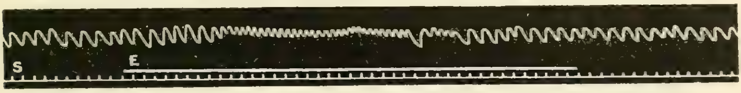

Fig. 147.—Acceleration of the Heart following Stimulation of the Cardiac Branches which come from the Annulus of Vieussens.

The Physiologic Action of the Vagus Nerve in Mammals.—In the mammal the same or similar effects result from stimulation of the vagus as in the frog. If the thorax of the dog is opened and artificial respiration maintained the heart will continue to beat in a practically normal manner for a long time. Under such conditions if the vagus nerve on one side be divided and its peripheral end stimulated with induced electric currents of moderate strength the heart will be seen to come to a standstill almost immediately in the condition of diastole, and may be so kept for a variable period, from fifteen to thirty seconds or more, during which its walls are relaxed and its cavities filled with blood. On cessation of the stimulation the contractions return and in a very short time the former rate and force of the beat are regained. If the electric currents are of feeble strength, the heart will come to rest gradually through a gradual diminution in the rate and force of the contraction. During the period of the inhibition the heart presents an appearance similar to that presented by the heart of the cold-blooded animal. When the heart of an animal is thus exposed, the auricle and the ventricle of one side may be attached by threads to writing levers and their contractions registered on a moving recording surface. The effects on both auricles and ventricles which follow vagus stimulation will then become more apparent. Fig. 148 is a tracing thus obtained. The animal employed was a rabbit.

The inhibitor effect of the vagus varies in degree and duration in different animals. In the dog the effect of vagus stimulation is usually pronounced, lasting from 15 to 30 seconds; in the rabbit it is perhaps equally well pronounced but somewhat less in duration; in the cat it is almost wanting. In this latter animal a complete standstill, even for a few seconds, is very rarely seen; usually there is produced merely a slight diminution in the rate of the beat even though the stimulus employed is quite strong. In all these animals, however, after a very short time the nerve impulses lose their inhibitor influence on the heart-muscle, and notwithstanding continued stimulation of the vagus, the heart returns to its former rate and vigor. This result is in marked contrast to that observed during stimulation of the vagus in the cold-blooded animals, in which the heart may be kept at rest for relatively very long periods of time. No satisfactory explanation

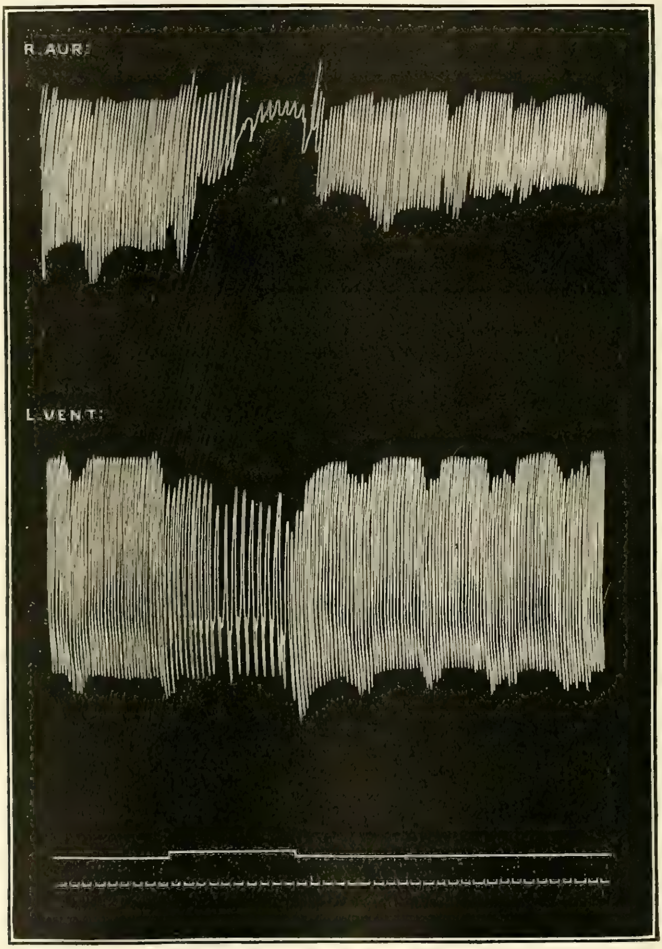

FIG. 148.—RESULT OF THE STIMULATION OF THE PERIPHERAL END OF THE DIVIDED LEFT VAGUS IN THE RABBIT.—(*Brodie.*)

for this loss of vagus control or escape of the heart from the vagus control has as yet been offered.

Seat of Action of the Vagus Impulses.—In a foregoing experiment of which Fig. 148 is a graphic result, stimulation of the left vagus with a fairly strong current was followed by a diminution in both the rate and force of the contraction of both auricles and ventricles, though the effect was most marked in the auricles. From this and similar facts it has come to be the general belief that the inhibitor nerve impulses exert their influence mainly, if not exclusively, on the auricle, and that the cessation of ventricular action is a secondary effect due to the non-arrival across the conducting apparatus of the normal excitation process from the auricle. This is the case undoubtedly in the cold-blooded animals, and the experiments of Erlanger on the heart of the dog indicate that the same holds true for the mammals. This investigator has found that when the auriculo-ventricular tissues are suddenly clamped, including presumably the muscle band of His, there is for a time a complete cessation of ventricular activity, but after a variable period of time, fifty seconds or more, the ventricle develops an independent rhythm which gradually increases in frequency, but seldom , if ever, attains that of the auricles. Under such circumstances tetanic stimulation of the auriculo-ventricular tissues by means of the clamp now transformed into stimulating electrodes, failed to bring about a stoppage of the ventricles. Moreover, if during the time the clamp is applied and after the ventricle has developed a rhythm of its own, the vagus is stimulated, the auricles will cease to beat as usual, but the ventricles will continue to beat at their usual rate. These and similar facts lead to the conclusion that vagal inhibitor action is limited to the auricles.

From the foregoing facts it is apparent that the accelerator and augmentor effects of the sympathetic nerve impulses, and the inhibitor effects of the vagus nerve impulses, closely resemble on the one hand the accelerator and augmentor effects of increasing amounts of diffusible calcium salts, and on the other hand the inhibitor effects of increasing amounts of diffusible potassium salts in the blood or other circulating fluid; and so closely do these two sets of phenomena resemble each other, that they are by some observers regarded as identical.

Some additional facts in this connection have been presented by Howell, viz., that an increase (within limits) and a decrease in the percentage of diffusible calcium salts in a circulating fluid passing through the cavities of the mammalian (cat) heart, increases on the one hand, and decreases on the other hand, the sensitiveness of the heart to sympathetic acceleration and augmentation. From this the inference is deduced that the acceleration and augmentation of the heart-beat which follow stimulation of the sympathetic nerves are due to the presence in the heart tissue of a certain percentage of diffusible calcium salts, which have been freed from combination with organic matter by the action of the sympathetic nerve impulses.

Again, that an increase (within limit) and a gradual decrease in the percentage of diffusible potassium salts in a circulating fluid passing through the cavities of the frog and the cat heart, increases on the one hand and decreases and finally abolishes on the other hand the sensitiveness of the heart to vagus inhibition. From this the inference is deduced that the inhibition of the heart-beat which follows stimulation of the vagus nerve is due to the presence in the heart tissue of a certain percentage of diffusible potassium salts, which have been freed from combination with organic matter by the action of the vagus nerve impulses.

The Cardio-accelerator Center.—The collection of nerve-cells from which the pre-ganglionic fibers of the sympathetic system arise is known as the cardio-accelerator or augmentor center. The exact location of this center in the central nerve system has not been as yet accurately determined. It is probably located in the medulla oblongata.

From experiments which have been made on the sympathetic nerve apparatus in its entirety, it is believed that the function of this center is the discharge of nerve impulses which, conducted to the heart by the pre-ganglionic and post-ganglionic sympathetic fibers, cause an acceleration in the rate or an augmentation in the force, or both, of the heart-beat. It is also generally believed since the publication of Hunt's investigations that this center is in a state of tonic activity. This is shown by the fact that after the division of the vagus nerves and the removal of all inhibitor influences, division of the sympathetic nerves or extirpation of the stellate or inferior cervical ganglion, is yet followed by a *decrease* in the rate of the heart-beat. After division of the sympathetic nerves and the removal of accelerator influences it is also easier to bring about inhibition through vagus stimulation.

The Factors which Determine the Activity of the Cardio-accelerator Center.—The question has been raised as to whether the tonic activity of this center is maintained by *central* or *peripheral* stimuli, *i. e.*, whether it is maintained by causes within itself, the result of an interaction between the constituents of the cell substance and those of the surrounding lymph, or whether it is maintained by nerve impulses reflected to it through various afferent or sensor nerves. Inasmuch as there is no way of determining whether the causes are central, except by dividing all afferent nerves, it is impossible to state how much influence is to be attributed to this factor. On the contrary, though it is readily demonstrable that stimulation of many afferent nerves will cause an acceleration of the heart it can not be stated positively that this is the result of a reflex stimulation of the accelerator center. Though earlier investigators believed this to be the correct interpretation, the more recent experiments of Hunt apparently disprove it; for this investigator has shown that if the vagus nerves are divided it is impossible to produce reflex acceleration of the heart.

His conclusion, confirming that of others, is that cardiac acceleration is the result of an *inhibition* of the cardio-inhibitor center. A freer play to the tonic activity of the accelerator center would thus be made possible.

The Cardio-inhibitor Center.—The collection of nerve-cells from which the small efferent fibers of the vagus nerve arise is known as the *cardio-inhibitor* center. It is situated in the medulla oblongata and more especially in the gray matter beneath the floor of the fourth ventricle near the tip of the calamus scriptorius. It is in all probability, a part of the nucleus ambiguus.

From the experiments which have been made on the vagus inhibitor apparatus in its entirety it is believed that the function of this center is the discharge of nerve impulses, which conducted to the heart by the vagus fibers cause an inhibition of its beat of greater or less extent. In the dog, and probably in many other mammals, this center exerts a more or less constant inhibitor or restraining influence on the heart's activity. This is indicated by the fact that the rate of the beat is very much increased by simultaneous division of both vagi. The degree of the inhibition which this center exerts varies greatly, however, in different animals. In the cat and in the rabbit the inhibitor control is normally so slight that there is but a relatively slight increase in the rate of the beat after division of the vagi. The tone of the vagus in these animals is, therefore, said to be slight or feeble. In human beings the tone of the inhibitor apparatus is poorly developed in early childhood, as shown by the fact that the administration of atropin, which removes temporarily inhibitor control is not followed by an increase in the rate of the beat. It develops steadily and reaches a maximum at from the twenty-fifth to the thirtieth year. In advanced years the tone again declines. For these and other reasons it is believed that this center is in a state of tonic activity in many if not all mammals, discharging nerve impulses which exert a regulative influence on the cardiac mechanism in accordance with its needs and especially in reference to the variable resistances offered to the flow of blood which the heart must overcome.

The Factors which Determine the Activity of the Cardio-inhibitor Center.—The question has also been raised as to whether the tonic activity of this center is maintained by *central* or *peripheral* stimuli, *i. e.*, whether it is maintained by causes within itself the result of an interaction between the constituents of the cell substance and those of the surrounding lymph, or whether it is maintained by nerve impulses reflected to it through various afferent or sensor nerves. Though both factors play an important part in the maintenance of its activity, the trend of evidence points to the conclusion that the reflected impulses are by far the more important of the two. This latter supposition is supported by the results of direct experimentation upon sensor nerves in almost any region of the body. Thus stimulation of the dorsal roots of the spinal nerves, the trunks of the cranial sensor nerves, the splanchnic nerves, the pulmonary branches of the vagus, etc., gives rise to a more or less pronounced inhibition of the heart. As a rule, stimulation of the peripheral terminations of these nerves is more effective than stimulation of their trunks, hence an explanation is at hand for the cardiac inhibition which results from sudden distention of the stomach and intestines, or operative procedures in the nose, mouth, and larynx.

Reflex inhibition of the heart, even to the stage of absolute and permanent standstill, eventuating in the death of the individual is a not infrequent result of peripherally acting causes of a pathologic or operative character. From the results of experimental procedures the inference is drawn that normally, nerve impulses, developed by the action of physiologic causes, are reflected continuously from many peripheral regions of the body, which falling into this center gently stimulate and maintain it in a condition of necessary tonicity or activity.

The Causes of the Variations in the Heart-beat.—It has been stated elsewhere in the text (page 286), that the rate of the heart-beat is influenced by age, muscle activity, the position of the body, meals, variations in blood pressure, etc. In addition to these factors there is abundant evidence that other factors, *e. g.*, the action of peripheral stimuli of a physiologic or pathologic character in various regions of the body, can and do cause reflexly at one time or in one individual an acceleration of a marked character, and at another time or in another or the same individual an inhibition which may be so pronounced as to lead to a complete standstill in diastole. The records of clinical medicine contain many instances which show that gastric, intestinal, uterine and other organic disorders as well as various operative procedures in different regions of the body cause now an acceleration, now an inhibition of the heart.

The first explanation, that acceleration of the heart, the result of a peripherally acting stimulus, is due to a stimulation of the cardio-accelerator center by the arrival of nerve impulses coming through afferent nerves, having been made questionable and improbable by the results of Hunt's experiments, the alternate explanation must be, that the acceleration is due to an *inhibition* of the normal activity of the cardio-inhibitor center, and that inhibition is due to an *excitation* of the normal activity of the cardio-inhibitor center, and hence there follows the corollary that afferent nerves contain two sets of nerve-fibers which are in physiologic relation with the cardio-inhibitor center, one of which when stimulated peripherally inhibits its activity, the other of which when stimulated excites or augments its activity.

The extent to which both sets of fibers are present in any one afferent nerve is unknown. In the trigeminus it is believed the excitator fibers preponderate for the reason that peripheral stimulation of this nerve is followed by inhibition of the heart; in the sciatic, it is believed the inhibitor nerves preponderate, for the reason that stimulation of the central end of the divided nerve is followed generally by acceleration of the heart.

It is probable from the effects which follow gastro-intestinal disorders, that the vagus nerve contains both classes of fibers as represented in Fig. 141, inasmuch as stimuli of a pathologic character in one individual may reflexly excite or increase the activity of the cardio-inhibitor center, to be followed by an inhibition of the heart; and in another individual, may reflexly inhibit the activity of the same center and to such an extent that the cardio-accelerator center may be enabled to increase either the rate or the force or both, of the heart movements. Palpitation of the heart from gastric irritation might thus be explained.

The Influence of Psychic States.—The cardio-inhibitor and the cardio-accelerator centers may be increased in activity also by nerve impulses descending from the cerebrum, the result of emotional states; thus depressing emotions according to their intensity may so increase the activity of the cardio-inhibitor center, that the heart's action may not only be retarded but even completely inhibited; joyous emotions, on the contrary, may so increase the activity of the cardio-accelerator center or what is more probable inhibit the activity of the cardio-inhibitor center that the heart's action will be increased in both its rate and force.

From the results of stimulation of the sympathetic (accelerator) and vagus (inhibitor) nerves under a great variety of conditions it has been established that their respective centers are mutually antagonistic; that the activity of the accelerator center at one moment limits the activity of the inhibitor and at another moment is limited in turn by it; that the rate of the heart-beat at each moment is the resultant of the relative degree of activity of the two centers.

The Depressor Nerve.—The vagus trunk also contains afferent fibers stimulation of which not only brings about a reflex inhibition of the heart, but also a dilatation of the peripheral arteries and a fall of blood-pressure through a depressive influence on the vaso-motor centers. To this nerve the term depressor has been given. A consideration of the physiologic action of this nerve will be found in the section devoted to the nerve mechanisms concerned in the maintenance of the blood-pressure.

Modifications of the Nerve Mechanism of the Heart due to the Physiologic Action of Drugs.—The functions of different parts of the nerve mechanism of the heart may be demonstrated by an analysis of the effects which follow the administration of slightly toxic doses of the alkaloids of various drugs. The effects can be shown to be due to a stimulation or to a depression of the normal activity of one or more portions of the mechanism. The alkaloid may exert its specific action on the central portions in the medulla, or on the peripheral portions in the heart, or on both simultaneously. The heart-muscle may at the same time be stimulated or depressed in its action either in the same or in the opposite direction to that of the nerve mechanism. As a result the heart-beat may be increased or decreased both in rate and force.

The following examples will illustrate the action of alkaloids in general.

Atropin.—After the administration of atropin in sufficient amounts the heart-beat increases in frequency in all animals in which the cardio-inhibitor centers exert a steady inhibitor influence over the heart. This is especially true in man and the dog. In animals in which the inhibitor control is slight, as the rabbit and frog, the increase in frequency is not very marked. In all animals thus far experimented on after the administration of atropin, neither stimulation of the trunk of the vagus nor stimulation of the intra-cardiac ganglia will arrest or even retard the heart-beat. The inference, therefore, is that the alkaloid exerts its action upon the ganglion cells and their terminal branches, impairing their chemic integrity and abolishing their normal function, that of conducting nerve impulses from the vagus nerve proper to the heart-muscle. In consequence of this, the influence of the cardio-inhibitor center is cut off and the cardio-accelerator being unopposed in its activity, the rate of the beat is increased. After a variable period the heart returns to its normal rate. Stimulation of the vagus is again followed by the usual inhibition. As atropin is partly oxidized, and partly excreted, it is assumed that the nerve terminals have been restored by nutritive forces to their normal condition and their conductivity regained. This having been accomplished the vagus nerve impulses can again reach the heart-muscle and the cardio-inhibitor center is therefore enabled to re-establish inhibitor control and antagonize the activity of the cardio-accelerator center.

Nicotin.—After the administration of nicotin in sufficient amounts the heart-beat is primarily decreased in frequency even to the point of standstill in diastole for a few seconds, and secondarily increased both in frequency and force beyond the normal. If the vagus nerves be first divided this primary decrease is not so marked and the inference is that the alkaloid primarily stimulates the cardio-inhibitor center and increases its normal function and perhaps the terminal branches of the vagus fibers, the pre-ganglionic, as well. After the secondary increase in the rate is established stimulation of the vagus trunk fails to inhibit the heart, though stimulation of the intra-cardiac ganglia is at once followed by the usual inhibitor phenomenon, arrest of the heart in diastole. For this reason it is believed that nicotin acts on the peripheral terminations of the pre-ganglionic fibers of the vagus as they arborize around the intra-cardiac ganglia, depressing them and suspending their normal function, that of conducting nerve impulses from the vagus to the ganglion cells. Since stimulation of the pre-ganglionic fibers of the accelerator apparatus fails to accelerate the rate of the heart-beat, though stimulation of the post-ganglionic fibers has the usual accelerating effect, the inference is that nicotin acts upon and suspends the conductivity of their terminal branches in the ganglia. The acceleration of the heart must therefore be attributed either to a stimulation of the post-ganglionic fibers or of the cardiac muscle itself (Cushney).

Pilocarpin and Muscarin.—These alkaloids, whether administered internally or applied locally to the heart, diminish the frequency and the force of the beat to such an extent that it very shortly comes to rest in diastole. For the reason that the internal administration or the local application of atropin in proper doses, which has a depressive action on the intra-cardiac cell terminations, removes the inhibition and restores the normal rhythm, the inference is drawn that both these alkaloids either increase the irritability of the nerve-cells or heighten the conductivity of their terminal fibers. The return of the heart-beat is attributed to a decline in irritability to the normal level in consequence of the antagonistic action of the atropin.

Digitalin.—The administration of digitalin gives rise to effects, the character and extent of which vary in different animals. In the frog, as a rule, the only effect produced is a gradual increase in the duration and force of the ventricular systole, with a corresponding decrease in the duration of the diastole, until the heart comes to rest in the systolic state. As this effect is observed after division of the vagus trunk and also after the suspension of the activity of the intra-cardiac cell-fibers by atropin, it is evidently due to a direct stimulation of the heart-muscle. In some instances, however, the opposite effect is produced, viz., a gradual increase in the length of the diastole, a decrease in the duration of the systole, until the heart comes to rest in the diastolic state. As this effect only arises when the vagus nerve is intact it is very probably due to a stimulation of the cardio-inhibitor center and a consequent increase of its functional activity. Though either effect may be produced in the frog the predominant effect is the increase in the contraction of the heart-muscle rather than an inhibition of the beat.

In mammals both effects are observed, viz., a diminution in the rate of the beat, a lengthening of the diastole and an increase in the vigor of the systole, which are evidently due to a simultaneous stimulation of the cardio-inhibitor center and of the cardiac muscle. Digitalin thus expends itself on two opposing mechanisms; as to which gains the ascendency will depend on the dosage and the character of the animal.

CHAPTER XIV.

THE CIRCULATION OF THE BLOOD (Continued).

THE VASCULAR APPARATUS: ITS STRUCTURE AND FUNCTIONS.

The systemic vascular apparatus consists of a closed system of vessels extending from the left ventricle to the right auricle, and includes the arteries, capillaries, and veins. Though serving as a whole to transmit blood from the one side of the heart to the other, each one of these three divisions has separate but related functions, which are dependent partly on differences in structure and physiologic properties, and partly on their relation to the heart and its physiologic activities.

The Structure, Properties and Functions of the Arteries.—The arteries serve to transmit the blood ejected from the heart to the capillaries; that this may be accomplished they divide and subdivide and ultimately penetrate each and every area of the body. Their repeated division is attended by a diminution in size, a decrease in the thickness and a change in the structure of their walls.

A typical artery consists of three coats: an internal, the *tunica intima;* a middle, the *tunica media;* an external, the *tunica adventitia.*

The internal coat consists of a structureless elastic basement membrane, on the inner surface of which rests a layer of elongated spindle-shaped endothelial cells. The middle coat consists of several layers of circularly disposed, non-striated muscle-fibers, between which are networks of elastic fibers. The external coat consists of bundles of connective tissue of the white fibrous and yellow elastic varieties. Between the external and middle coats there is an additional elastic membrane. In the small arteries there is but a single layer of muscle-fibers. In the large arteries the elastic tissue is very abundant, exceeding largely in amount the muscle-tissue. It is also more closely and compactly arranged. The external coat is well developed in the large arteries (Figs. 149 and 150).

In virtue of the presence in their walls of both elastic and contractile elements, the arteries possess the two properties of elasticity and contractility.

The *elasticity* is especially well developed in the large arteries, which are capable, therefore, of both distention and elongation, and, when the distending force is withdrawn, of returning to their previous condition. The elasticity permits of a wide variation in the amount of blood the arterial system can hold between its minimum and maximum distention. Thus the capacity of the aorta and carotid artery of the rabbit can be increased four times and six times respectively by raising the intra-arterial pressure from 0 to 200 mm. of mercury. The elasticity also converts the intermittent movement of the blood imparted to it by the heart as it is ejected from the ventricle, into a remittent movement in the arteries and finally into the continuous and equable movement observed in the capillaries. This is accomplished in the following manner: With each contraction of the left ventricle more blood is ejected into the aorta than the arteries can discharge into the capillaries and veins during the time of the contraction. The portion not so discharged exerts a lateral pressure against the walls of the arteries which at once dilate until a condition of equilibrium is established between the pressure from within and the elastic reaction of the arterial walls from without. With the cessation of the contraction the elastic walls recoil and propel the blood toward the capillaries. The intermittent action of the heart is thus succeeded by the continuously reacting arterial wall.

As the blood advances toward the periphery of the arterial system and larger amounts pass into the capillaries, both the distention and the elastic recoil diminish, and by the time the blood reaches the capillaries its intermittency of movement has been so far obliterated by the elastic recoil, that as it enters the capillaries the movement becomes equable and continuous. The elasticity thus serves the purpose of equalizing the movement of the blood throughout the arterial system.

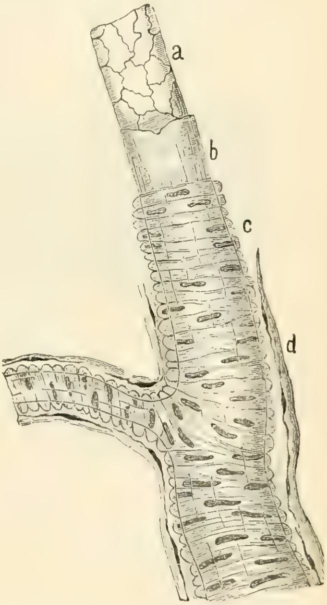

FIG. 149.—COATS OF A SMALL ARTERY. *a.* Endothelium. *b.* Internal elastic lamina. *c.* Circular muscular fibers of the middle coat. *d.* The outer coat.—(*Landois and Stirling.*)

In youth the arterial walls are highly distensible and elastic; in advanced years they are frequently relatively rigid and inelastic; and in consequence the flow of blood toward and into the capillaries approximates in its characteristics the flow of a fluid through a rigid tube under the intermittent action of a pump; that is, the intermittent movement imparted by the heart is not so completely converted into a continuous movement, and hence the blood flows through the capillaries during the systole with greater velocity, and during the diastole with less velocity, than is the case when the vessel is normally elastic. For these and other reasons the tissues are not so well nourished and hence their nutrition and functional activities decline.

The *contractility* permits of a variation in the amount of blood passing into a given capillary area in a unit of time. Normally each artery has a certain average caliber due to a given contraction of the muscle coat. Beyond this average condition the artery can pass in one direction or the other by either a relaxation or increased contraction of the muscle coat. During the functional activity of any organ or tissue there is need for an increase in the amount of blood beyond that supplied during functional inactivity or rest. This is accomplished by a relaxation of the muscle-fibers. With the cessation of activity the muscle-fibers again contract and reduce the amount of blood to that required for nutritive purposes only. An increased contraction of the muscle-fibers beyond the average, diminishes the outflow of blood, and if sufficiently great may give rise to anemia and pallor. The contractile elements at the periphery of the arterial system, in the so-called *arteriole* region, therefore regulate the supply of blood to the tissues in accordance with their functional needs.

Moreover, as will be stated in subsequent paragraphs the degree of contraction of the arteriole muscle influences very markedly the degree of friction which the blood has to overcome in passing from the arteries into the capillaries. If the muscle contracts vigorously the caliber of the arteriole is diminished and the friction increases; if the muscle relaxes, the caliber of the arteriole is augmented and the friction decreases. By virtue of its tonic activity, the arteriole muscle at the periphery of the arterial system offers considerable resistance to the outflow of the blood and which is therefore spoken of generally as the peripheral resistance, though there is included under this term the resistance, offered by the small caliber of the capillary blood-vessel as well. This latter factor is constant, the former variable.

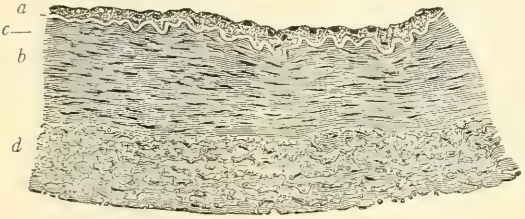

FIG. 150.—TRANSVERSE SECTION OF PART OF THE WALL OF THE POSTERIOR TIBIAL ARTERY (MAN). —(*Schäfer.*) *a*. Endothelium lining the vessel, appearing thicker than natural from the contraction of the outer coats. *b*. The elastic layer of the intima. *c*. Middle coat composed of muscle-fibers and elastic tissue. *d*. Outer coat consisting chiefly of white fibrous tissue.—(*From Yeo's "Physiology."*)

The Structure, Properties and Functions of the Capillaries.—The capillaries are small vessels that connect the arteries with the veins. Though different in structure from a small artery or vein, there is no sharp boundary between them, as their structures pass imperceptibly one into the other. A true capillary, however, is of uniform size in any given tissue and does not undergo any noticeable decrease in size from repeated branchings. The diameter varies in different tissues from 0.0045 mm. to 0.0075 mm., just sufficiently large to permit the easy passage of a single red corpuscle. The length varies from 0.5 mm. to 1 mm. The wall of the capillary (Fig. 151) is composed of a single layer of nucleated endothelial cells with serrated edges united by a cement material. Though extremely short, the capillaries divide and subdivide a number of times, forming meshes or networks, the closeness and general arrangement of which very in different localities.

As the endothelial cells are living structures and characterized by irritability, contractility and tonicity, it may be assumed that the capillary wall as a whole is characterized by the same properties. Upon the possession of these properties, the functions of the capillary depend.

The *function* of the capillary wall is to permit of a passage of the nutritive materials of the blood into the surrounding tissue spaces and of waste products from the tissue spaces into the blood. The structure of the capillary wall is well adapted for this purpose. Composed as it is of but a single layer of endothelial cells, the thickness of which defies accurate measurement, it readily permits, under certain conditions, of the necessary exchange of materials between the blood and the tissues. The forces which are concerned in the passage of materials across the capillary wall are embraced under the terms *diffusion*, *osmosis*, and *filtration*. As a result of the interchange of materials the tissues are provided with nourishment and relieved of the presence of waste products. The blood at the same time changes to a variable extent in chemic composition; because of the loss of oxygen and the gain of carbon dioxid it also changes in color from red to bluish-red.

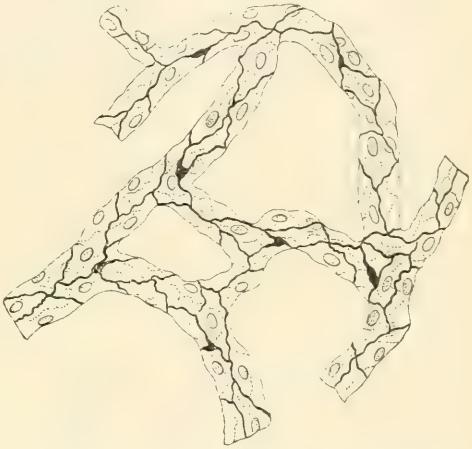

FIG. 151.—CAPILLARIES. THE OUTLINES OF THE NUCLEATED ENDOTHELIAL CELLS WITH THE CEMENT BLACKENED BY THE ACTION OF SILVER NITRATE.—(*Landois and Stirling.*)

In order that the nutritive materials may pass through the capillary wall in amounts sufficient to maintain the necessary supply of lymph in the lymph or tissue spaces, it is essential that the blood shall flow into and out of the capillary vessels constantly and equably, in volumes varying with the activities of the tissues, under a given pressure and with a definite velocity. These conditions are made possible by the coöperation of the physical properties and physiologic functions of the heart and vascular apparatus, the nature of which will be explained in subsequent pages.

The Structure, Properties and Functions of the Veins.—The veins serve to collect the blood from the capillary areas and return it to the right side of the heart. As they emerge from the capillary areas the veins, which in these regions are termed venules, are quite small. By their convergence and union the veins gradually increase in size in passing from the periphery toward the heart. Their walls at the same time correspondingly increase in thickness. The veins from the lower extremities, the trunk, and abdominal organs finally terminate in the inferior vena cava. The veins from the head and upper extremities terminate in the superior vena cava. Both venæ cavæ empty into the right auricle.

A typical vein consists of the same three coats as the artery: viz., the *tunica intima*, the *tunica media*, and the *tunica adventitia*. The *media*, however, does not possess as much of either the elastic or muscle tissue as the artery, but a larger amount of the fibrous tissue. Hence they readily collapse when empty. In virtue of their structure the veins also possess both *elasticity* and *contractility*, though in a far less degree than the arteries. These properties come into play and are of value in furthering the movement of the blood toward the heart, especially after a temporary obstruction.

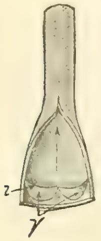

FIG. 152. VALVES OF A VEIN. *v.* Semilunar valve. *i.* Free edge of the valve. — (*Davidson.*)

Veins are distinguished by the presence of valves throughout their course. These are arranged in pairs and formed by a reduplication of the internal coat, strengthened by fibrous tissue. They are always directed toward the heart and in close relation to the walls of the veins, so long as the blood is flowing forward (Fig. 152). An obstruction to the flow causes the valves to turn backward until they meet in the middle line, when they act as a barrier to regurgitation. Under these circumstances the elastic tissue permits the veins to distend and accommodate the blood. With the removal of the obstruction the recoil of the elastic tissue, and perhaps the contraction of the muscle-tissue, forces the blood quickly onward.

HYDRODYNAMIC CONSIDERATIONS.

The blood flows through the arteries, capillaries and veins in accordance with definite laws. During its transit certain phenomena are presented by each of these three divisions of the vascular apparatus. Since these phenomena, as well as the laws which govern them are similar to, though more complex than the phenomena presented by relatively simple tubes with rigid or elastic walls, while liquids are flowing through them under a steadily acting or an intermittently acting pressure, it will be conducive to clearness of conception of the mechanics of the vascular apparatus, if there be considered:

1. The flow of a liquid through a horizontal tube with rigid walls and of uniform or variable diameter under a steadily acting pressure, and

2. The flow of a liquid through a tube with elastic walls under an intermittently acting pressure.

THE FLOW OF A LIQUID THROUGH A HORIZONTAL TUBE WITH RIGID WALLS.

The phenomena and the laws which govern them, that attend the flow of a liquid through a rigid tube of uniform diameter under a steadily acting pressure may be readily observed in an apparatus similar to that represented in Fig. 153, which consists of a reservoir or pressure vessel, *P*, provided with a horizontal tube into which is inserted at equal distances a series of vertical tubes. If the reservoir be filled with a liquid, water for example, the latter under certain conditions will exert a downward pressure and act as a propelling or driving power, the degree of which will depend on the height of the column and may be represented by *H*. If the stopcock at *O* be opened the column of water, which has heretofore been exerting an equal pressure in all directions, will now exert a downward pressure only, and in consequence it will be driven into and through the horizontal tube and discharged from its free extremity with a definite velocity. The velocity can be determined by measuring the quantity, q, discharged in a given time, t, (1 sec.) and dividing it by the area of the tube, πr^2; *e.g.*, $v = \frac{q}{\pi r^2}$ Moreover in a tube of uniform diameter the velocity through each cross-section will be the same.

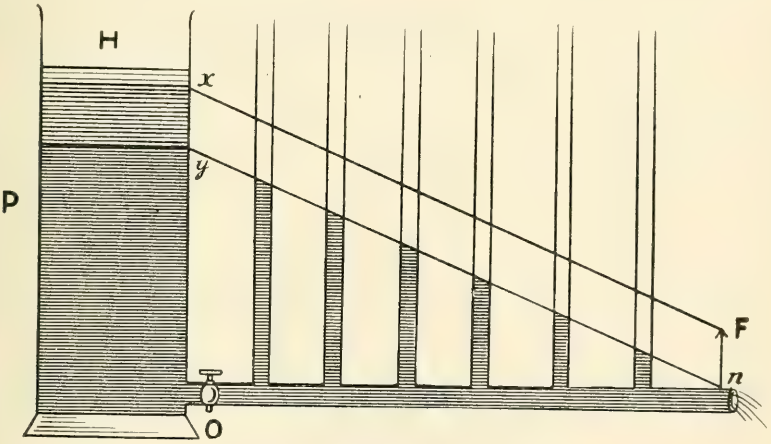

FIG. 153.—A PRESSURE VESSEL, *P*, with an outflow horizontal tube, *O–n*, into which vertical tubes or manometers are inserted.

As the water flows through the horizontal tube it meets with resistance, namely, the cohesion and friction of its molecules, and which must be overcome if the flow is to continue. Because of the fact that water will moisten most surfaces with which it comes in contact there will be an adhesion between the walls of the tube and the outer layer of the column of water, in consequence of which it will become more or less stationary. Between the outer stationary layer and the axis of the stream, there is an infinite number of layers of molecules, the cohesion of which one for the other steadily diminishes in passing from the periphery to the center of the stream. The extent of this cohesion will increase as the tube is lengthened, and decrease as it is widened. In tubes of large diameter the axial cohesion is slight and hence the friction of the molecules, the resistance to the flow, is readily overcome; in the tubes of small diameter the axial cohesion is relatively great and the resistance less easily overcome.

As a result of the resistance the forward movement of the water under the pressure in P is somewhat retarded, and as a consequence it will exert a lateral or radial pressure against the walls of the tube, as shown by the rise of the water in the vertical tubes. The amount of the lateral pressure at any given point is indicated and measured by the height to which the water rises. For this reason these tubes are termed pressure tubes or piezometers.

Since the resistance in a tube of uniform diameter is proportional to its length the lateral pressure will gradually but progressively decrease from the reservoir to the outlet. Therefore the pressure at any given point is proportional to the resistance yet to be overcome and conversely the resistance to be overcome is indicated by the height of the pressure. (In the conduct of an experiment the propelling power should be kept constant by permitting fluid to flow into the reservoir as rapidly as it flows out of the horizontal tube.)

The power or force which overcomes the resistance in the horizontal tube and imparts velocity to the fluid is the downward pressure of the water in the reservoir, represented by H. The amount of this power utilized in overcoming the resistance is approximately indicated by the height of the fluid, y, at which point the line uniting the upper limits of the water in the vertical tubes intersects it. The height of the fluid at this point is a measure, therefore, not only of the resistance but also an indication of the relative amount of the pressure used in overcoming it and is therefore known as the *pressure* height.

The amount of the pressure consumed in imparting the observed velocity is determined by ascertaining the height from which a particle must fall in empty space to acquire this velocity. This is obtained by dividing the square of the velocity by twice the accelerating force of gravity as expressed in the formula, $\frac{v^2}{2g}$; the quotient is the height and is known as the velocity height. Conversely if the moving fluid were discharged into empty space through an opening in the tube at n, it would ascend an equal distance. If now this height is represented by F, and a line be drawn from it, parallel to the line of pressure until it meets the reservoir at x, it will be seen what percentage, $x\ y$, of the primary propelling power is consumed in imparting the observed velocity.

Of the total pressure a small portion is left over which is utilized in forcing into, and overcoming the resistance offered by, the orifice of the horizontal tube. The initial pressure in P therefore divides itself into two portions; one, the larger by far, is utilized in overcoming the resistance to the flow of the water; the other, the smaller, in imparting velocity.

Thus the two phenomena presented by the flow of a liquid through a tube with rigid walls and of uniform diameter are velocity and pressure, of which the former is the same for each cross-section, and the latter at any point directly proportional to the resistance to be overcome.

If, instead of a horizontal tube of uniform diameter, there be substituted a tube, the middle third of which is enlarged, the conditions will be the same as in the previous case until the fluid flows into the enlarged portion, when the velocity will diminish and will become inversely proportional to the area of the cross-section. The resistance will be also diminished and as a result the pressure rises or at least less of the initial pressure is utilized in this than in the first section of the tube. When the liquid flows into the narrow or third section, the primary velocity returns. Though the resistance again increases the amount to be overcome is small, and hence there is a rapid and steady fall of pressure.

On the contrary, if a tube be substituted, the middle third of which is narrowed, the conditions will be the same as in the previous cases until the liquid flows into the narrowed section, when at once the velocity increases and becomes inversely proportional to the area of the cross-section; the resistance being increased at the same time, there will be a rapid consumption and a steep fall of pressure. On flowing into the third section, the velocity again diminishes and the pressure falls though less slowly to the end of the tube.

THE FLOW OF A LIQUID THROUGH A SERIES OF BRANCHING AND AGAIN RE-UNITING TUBES WITH RIGID WALLS.

In a system of this character, such as represented in Fig. 154, there may be assumed as a result of the repeated branchings, a progressive increase in the total sectional area of the collective tubes coincident with a progressive decrease in the sectional area of individual tubes in the section B C, while in the section C D, there is a progressive decrease in the total sectional area of the collective tubes coincident with a progressive increase in the sectional area of individual tubes.

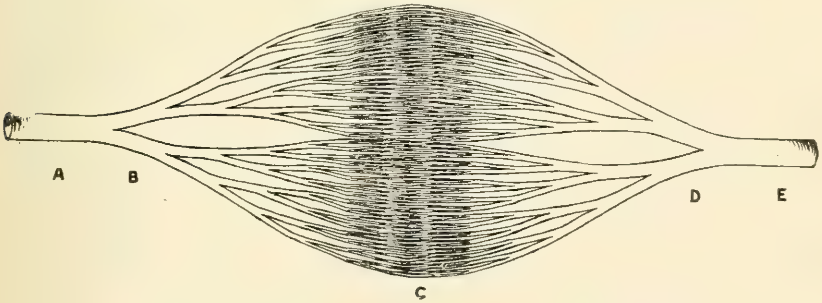

FIG. 154.—A SERIES OF BRANCHING AND AGAIN RE-UNITING TUBES.

Assuming the system to be connected with a pressure vessel, as in the preceding instance, but which has been omitted from the figure, and the stop cock to be suddenly opened, the column of water will now exert a downward pressure, and in consequence the water will be driven into and through the system with a definite velocity and pressure.

The velocity of a fluid through such a system should theoretically be decreased from B to C in a ratio inversely proportional to the total area of each cross-section. This, however, will not be the case because of the presence of the angles formed by the repeated branchings which, as determined experimentally, simultaneously increase the velocity. The extent to which the initial velocity will be changed will therefore be proportional to the ratio between these two factors. If they balance each other there will be no change; according as the one or the other preponderates, there will be a corresponding decrease or increase in velocity.

In flowing from C to D the velocity will be changed in the opposite direction and for the reverse reasons and in E it will have regained the value it had in A, if the entrance and exit tubes are of the same diameter.

The lateral pressure should theoretically be increased from B to C because of the increase in the total sectional area and the consequent diminution of friction, but because of the increase in resistance due to the decrease in sectional area of individual tubes as well as by the angles formed by the branching of the tubes it will be simultaneously *decreased*. The extent to which the pressure will be changed will also be proportional to the ratio between these two factors. If they balance each other, there will be no change; according as one or the other preponderates will there be an increase or decrease in pressure. In passing from C to D the pressure will be changed in the same direction but for the reverse reasons.

In a general way it may be said that in a system in which the successive branchings are accompanied by a progressive decrease in diameter, the influence of an increase in the total sectional area on velocity will preponderate over that due to the production of angles, and hence the initial velocity will be decreased from B to C, and increased from C to D, for the reverse reasons; and if the tubes in the center of the system are capillary in character, the resistance offered by them and hence the consumption of the propelling power will preponderate over the decrease in resistance due to the widening of the stream bed, and hence as the liquid flows from B to C there will be a fall in pressure, and in flowing from C to D there will be an additional fall of pressure, owing to the narrowing of the stream bed and the increase in resistance, which is however slight in amount.

The pressure throughout this system is the result of the resistance to the flow of the water and the extent of the pressure in any one section will be proportional to the resistance yet to be overcome. It will naturally be high in the section A–B and low in the section D–E. The value of these two pressures in these sections and their relation to each other may be varied temporarily or permanently by the introduction along the course of the tubes between B and C of a series of stopcocks. If the lumen of each stopcock has a certain average value, so as to permit of a certain outflow of water, the pressure will have a certain value in both A–B and D–E. But if the lumen of each stopcock is decreased, there will be an increase in the resistance and hence a rise of pressure in A–B and a fall of pressure in D–E. If, on the contrary, the lumen of each stopcock is increased, there will be a decrease in the resistance and hence a fall of pressure in A–B and a rise of pressure in D–E. The stopcocks may be spoken of as a *variable peripheral resistance*.

In the foregoing exposition it has been assumed that in all instances the pressure in the pressure vessel was steadily acting. If, however, the pressure be made to act intermittently as it can be by alternately opening and closing the stopcock, both the velocity and the pressure will be alternately increased and decreased. The outflow of the fluid during the moment the pressure is acting will be rapid, and during the moment the pressure is not acting the outflow will cease. It becomes therefore intermittent. Coincidently there is an alternate temporary increase and decrease of the lateral pressure.

THE FLOW OF A FLUID THROUGH A TUBE WITH ELASTIC WALLS.

When a tube with elastic walls is connected with a pressure vessel, the conditions which are established on opening the stopcock and the consequent flow of water, will soon approximate those observed in a tube with rigid walls. As the water moves forward, it encounters friction, exerts a lateral pressure and causes a distention of the tube. This latter effect continues until the elastic recoil of the walls of the tube exactly counterbalances the pressure of the water from within. When this condition is established the tube becomes practically a tube with rigid walls, and hence so long as the primary pressure is uniform, the velocity and lateral pressure will obey the laws which hold true for rigid tubes.

If, however, the primary pressure be intermittently applied or alternately increased or decreased, and the water forced into the tube, previously filled with water but under no particular pressure, it will be forced out of the peripheral end of the tube more or less rapidly during the period of the increase of pressure and less rapidly during the period of the decrease of pressure or it may cease entirely. The extent to which the outflow becomes merely remittent, or entirely intermittent, will depend on the amount of resistance, whether this be due to length of tube or a narrowed outlet, and the degree of elasticity.

When these factors have a negative value the outflow will be intermittent. But if they are made to gradually change, and this is especially the case with the resistance, from a negative to a positive value, the outflow gradually changes from an intermittent to a remittent and finally to a continuous outflow and for the following reasons:

With a given resistance and elasticity, the fluid which is driven into the tube by the action of the primary pressure exerts more or less lateral pressure, gives rise to a distention of the tube and acquires a certain velocity of outflow. In consequence of the distention, a portion of the fluid accumulates. With the cessation in the action of the primary pressure, the elastic walls recoil and force the accumulated fluid forward and so maintain more or less effectively the same velocity of outflow until there is a return of the pressure. If the resistance and elasticity have a negative value this is impossible and the outflow will be entirely intermittent. But if they are made to increase in value, the proportionate amount of the fluid which accumulates during the action of the primary pressure will also increase in amount and hence there will be an increase in the distention of the tube. The elastic recoil will therefore be greater in amount and longer in duration, and hence the outflow will change to a remittent and finally to a continuous outflow.

Coincident with the action and cessation of action of the primary pressure there is a corresponding increase and decrease of the lateral pressure and when the intermittency in their action is sufficiently rapid, the excess of fluid entering the tube over that discharged becomes sufficiently great to maintain a certain average or mean pressure, which, however, undergoes an alternate increase and decrease with each variation in the primary pressure.

The temporary increase and decrease of the pressure and the consequent expansion and recoil of the tube in the neighborhood of the pressure vessel, gives rise to a wave on the surface of the fluid which is propagated with more or less rapidity—though with decreasing size from the beginning to the end of the tube and causing in each section a corresponding expansion and recoil, and known as the expansion wave.

THE APPLICATION OF THE FOREGOING FACTS TO THE VASCULAR APPARATUS.

The systemic vascular apparatus may be conceived of as a system of tubes which have symmetrically divided and subdivided and afterwards again united and reunited in a corresponding manner. The arteries, arterioles, capillaries, venules and veins may therefore be schematically arranged (Fig. 155) in a manner identical with the schematic arrangement of tubes represented on page 333. The heart, with which they are in connection, when filled with blood may be compared with the reservoir filled with water, and the intra-ventricular pressure developed during the contraction, to the downward pressure of the water when the stopcock at O is opened (See Fig. 153).

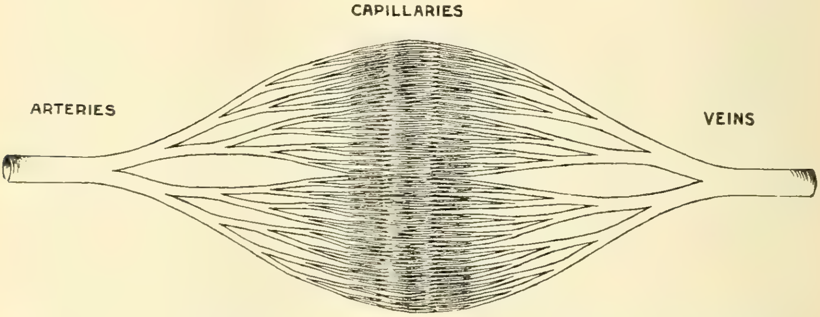

FIG. 155.—SCHEMATIC ARRANGEMENT OF THE VASCULAR APPARATUS.

The Stream-bed.—The stream-bed, the path along which the blood flows, varies widely in its total sectional area in different parts of its course, being least in the aorta and venæ cavæ, and greatest in the capillaries. In passing from the base of the aorta toward the capillaries the sectional area of individual arteries, in consequence of repeated branching, diminishes, though their total sectional area increases and in direct proportion to their distance from the heart. In the capillary system the sectional area of an individual capillary attains its minimal value, though the total sectional area attains its maximal value. Comparing one with the other, it has been estimated that the total sectional area of the aortic bed is to the total sectional area of the capillary bed as 1 is to 600 or 800. In passing from the capillary into the venous system the sectional area of individual veins increases, though the total sectional area decreases and in direct proportion to their distance from the capillaries.

The stream-bed in the aorta is relatively narrow, but widens gradually as it approaches the capillaries, where it attains its maximum width; it again narrows gradually as it passes into the veins, until in the venæ cavæ it becomes almost as narrow as in the aorta. As the combined sectional areas of the venæ cavæ are greater than the sectional area of the aorta, the stream-bed of the former never becomes as narrow as that of the latter.

The gradual increase in the width of the stream-bed from the beginning of the aorta to the middle of the capillary system, and the gradual decrease in the width of the stream-bed from the middle of the capillary system to the terminations of the venæ cavæ, which results from the repeated branching and subsequent reuniting, as well as its relative width in the arteries, capillaries and veins, is shown graphically in Fig. 156.

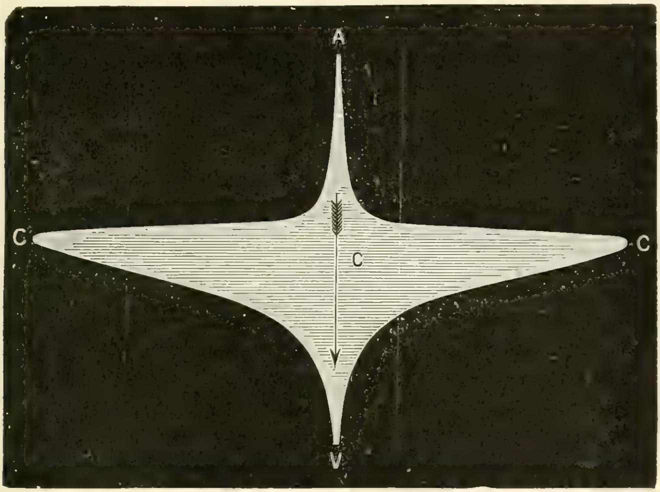

Fig. 156.—Diagram Designed to Give an Idea of the Aggregate Sectional Area of the Different Parts of the Vascular System. A. Aorta. C. Capillaries. V. Veins. The transverse measurement of the shaded part may be taken as the width of the various kinds of vessels, supposing them fused together.—(*Yeo.*)

When the heart contracts and when the intra-ventricular pressure rises above the pressure in the aorta, the aortic valves are forced open and the blood is driven into and through the arteries, capillaries and veins and empties into the right side of the heart with a definite velocity and pressure. Because of the fact that the stream-bed progressively increases in width from the aorta to the middle of the capillary system the velocity through each cross-section should theoretically be inversely proportional to its total sectional area. This, however, strictly speaking, is not the case, owing to the accelerating influence of the angles formed by the repeated branchings. But for the reason that the influence of the former factor so largely preponderates over the influence of the latter factor, it may be accepted that the initial velocity of the blood in the aorta gradually decreases inversely as the sectional area increases, until it attains its minimal value in the capillary system. The actual velocity is the resultant of these two opposing forces. For the reverse reason, viz., the narrowing of the stream-bed and the retarding influence of the angles, the velocity of the blood gradually increases from the middle of the capillary system to the end of the venæ cavæ though it will never attain its initial velocity in these vessels because their combined sectional areas are greater than that of the aorta. The accelerating effect of the narrowing of the stream-bed preponderates over the retarding effects of the angles and the velocity will be the resultant again of these two opposing forces. The same facts of course hold true for the pulmonic vascular apparatus.

In its passage through the vessels the blood meets with resistance, viz., the cohesion and friction of its molecules which must be overcome if the flow or the movement of the blood is to continue. The statements made in previous paragraphs regarding the causes and the results of friction in tubes with either rigid or elastic walls hold true for the most part also for the blood-vessels. As a result of friction the forward movement of the blood is somewhat retarded and in consequence will exert a lateral or radial pressure against the walls of the vessels, and from the facts previously stated, this pressure should diminish in a more or less progressive manner from the origin of the aorta to the ends of the venæ cavæ. That this is the case can be demonstrated for the arteries and veins at least by the insertion of pressure tubes and into which the blood can ascend. The height of the pressure at any given point in the system will be proportional to the resistance yet to be overcome.

Inasmuch as the stream-bed is not uniform in diameter the fall in pressure will not be uniform. As it enlarges in its middle portion the resistance lessens and theoretically there should be a rise of pressure in passing towards the capillary system, but as the repeated branching of the vessels is attended by an enormous diminution in the diameter of individual vessels, the resistance is proportionately increased and for this reason there should be a great consumption of the propelling power and a marked and rapid fall of pressure at the periphery of the arterial and throughout the capillary systems. That this is the case, though not to the extent it might be, is because the effect of the increase in resistance so largely preponderates over the effect of the increase in the width of the stream-bed. The actual fall of pressure is therefore the resultant of these two opposing factors. For the reverse reasons, however, viz., the narrowing of the stream-bed and the increase in the sectional area of individual tubes, there will be a further consumption of the propelling power and a further fall of pressure to the ends of the venæ cavæ. The effect of the increase in resistance of the rapidly narrowing stream-bed preponderates over the effect of the enlargement of diameter of individual vessels. The fall of pressure from the middle of the capillary system to the ends of the venæ cavæ will be again the resultant of these two factors.

The pressure throughout the vascular apparatus is, of course, the result of the resistance offered to the flow of the blood and therefore it will be high in the aorta and its main branches and low in the large veins. The amount and the relation of these two pressures in these two sections of the vascular apparatus can be temporarily or permanently changed in one direction or another by an increase or decrease in the resistance offered to the flow of blood from the arteries through the capillaries into the veins. This variation in the resistance is brought about by an increase or a decrease in the degree of the contraction of the arteriole muscles. Thus, if the muscle contraction increases, the resistance is increased and the pressure in the arteries rises; if, on the contrary, the muscle contraction decreases, the resistance diminishes and the pressure falls in the arteries and rises in the veins. The contraction of the arteriole muscle is spoken of as the *peripheral resistance.*

The Distribution of the Intra-ventricular Pressure.—The pressure developed during the ventricular contraction is thus expended in imparting velocity to the blood and overcoming the cohesion and friction of its molecules. The percentage of the pressure utilized in overcoming the resistance could be approximately determined from the pressure in the aorta if this were accurately known; the percentage of the pressure utilized in imparting velocity could be determined with the formula $\frac{v^2}{2g}$, if the actual velocity of the blood in the aorta could be experimentally determined. On account of the difficulty in obtaining this latter factor at least, the results must only be approximative.

An idea of the ratio between the velocity pressure and the resistance pressure, however, may be obtained from the distribution of the aortic pressure in the dog in reference to the carotid artery. Thus, if it be assumed that the average velocity of the blood is 35 cm., the velocity pressure is equal to $\frac{(35)^2}{1960}$ or 0.62 centimeters of blood or 0.046 centimeters of mercury, and if the average aortic pressure is 150 mm. of mercury, the ratio of the velocity pressure to the resistance pressure is as 1 to 326.

The phenomena which for the most part characterize the flow of blood through the blood-vessels are velocity and pressure, combined with an alternate expansion and recoil of the arterial vessels due to the intermittent character of the heart-beat. For special reasons it is convenient to consider the pressure first.

BLOOD-PRESSURE.

From theoretic considerations alone it may be inferred that the blood, as it flows through the vascular apparatus, exerts a pressure against the walls of the vessels, and that this pressure is greatest at the beginning of the aorta, and least at the ends of the venæ cavæ. The fact that the blood flows from the aorta to the venæ cavæ indicates that there is a higher pressure in the former than in the latter. The same holds true for the pulmonary artery and veins. So long as this is the case, the blood must flow from the point of high to the point of low pressure.

To this pressure the term blood-pressure is given, and may be defined as the pressure exerted radially or laterally by the moving blood-stream against the sides of the vessels. That there is such a pressure within the arteries, capillaries, and veins, different in amount in each of these three divisions of the vascular apparatus, is evident from the results which follow division of an artery or a vein of corresponding size. When an artery is divided, the blood spurts from the opening for a considerable distance and with a certain velocity. The reason for this lies in the fact that the vessel has been distended by the pressure from within and its walls thrown into a condition of elastic tension, so that at the moment there is an outlet, the vessel suddenly recoils and forces the blood out with a velocity proportional to the distention. When a vein is divided, the blood as a rule merely wells out of the opening with but slight momentum, and for the reason that the vessel has been but slightly, if at all distended by the pressure. These results indicate that the blood in the arteries stands under a pressure considerably higher than that of the atmosphere, while that in the veins stands under a pressure perhaps but slightly above that of the atmosphere. Especially true is this of the larger veins.

The same facts may be demonstrated in another and more striking way. A dog or cat is anesthetized and securely fastened in an appropriate holder. The carotid artery on the right side and the jugular vein on the left side are freely exposed and clamped. Into the artery there is inserted on the distal side of the clamp and in the direction of the heart a cannula to which is connected a tall glass tube, 200 cm. high and of about 4 mm. internal diameter. Into the vein there is passed on the proximal side of the clamp and in the direction of the capillaries a second cannula, to which is connected a similar tube, though of less height. If the two clamps are removed at the same time, the blood will mount in both tubes simultaneously. In the arterial tube the blood will ascend by leaps corresponding to the heart-beats until a certain height is reached, when the column becomes relatively stationary, being kept in equilibrium by the blood-pressure within the vessel and the atmospheric pressure without. Though stationary in a general sense, nevertheless, the blood-column oscillates, rising and falling with each contraction and relaxation of the heart. Not infrequently larger excursions of the column are seen which correspond in a general way to the respiratory movements. This experiment was originally performed on the horse, by the Rev. Stephen Hales (1732).

In the venous tube the blood also rises to a certain height, after which it remains quite stationary, as the effect of the cardiac contraction is not propagated under normal conditions beyond the arterial system. The height to which it rises is but slight as compared with that in the arterial tube. The pressure in both vessels is thus recorded in millimeters of blood. Strictly speaking the pressure thus obtained does not represent the *lateral* pressure in the carotid artery but in the vessel from which it arises. The central end of the carotid is, under the circumstances, but a continuation of the cannula and the pressure thus obtained is the lateral pressure of either the innominate artery or the aorta as the case may be. In order to obtain the lateral pressure in the carotid or any other artery it is only necessary to take the end pressure of any one of its branches or what amounts to the same thing, to divide the vessel and insert the horizontal portion of a T-shaped tube into the central and distal ends and through which the blood can continue to flow, and to connect the vertical portion with a vertical pressure tube or with a mercurial manometer. The absolute pressure on any given unit of vessel surface—*e. g.*, 1 sq. mm.—is obtained by multiplying the height of the column, expressed in millimeters, by the unit of surface, and then determining the weight of this mass of blood. Thus if the height of the column of blood in the carotid artery tube is 2000 mm., then the pressure on 1 sq. mm. is 2000 mm. of blood. The weight of 2000 c.mm. of blood is equal to 2.1 grams.

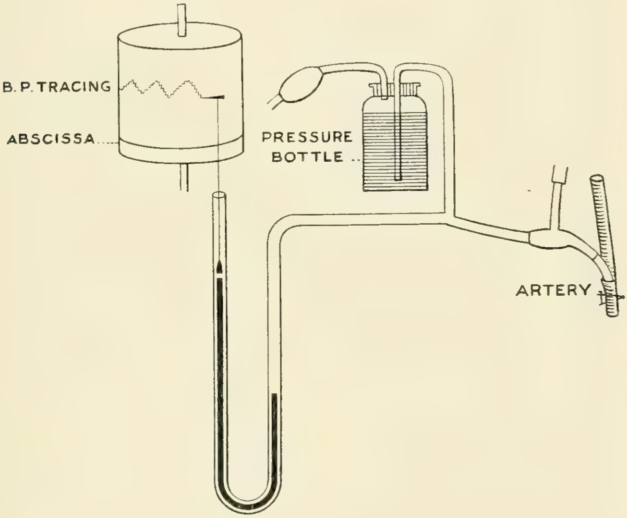

FIG. 157.—DIAGRAM TO SHOW THE RELATION OF THE MERCURIAL MANOMETER TO THE ARTERY, ON ONE HAND, AND TO THE RECORDING CYLINDER, ON THE OTHER HAND, WHEN ARRANGED FOR RECORDING BLOOD-PRESSURE.

The Arterial Blood-pressure.—For accurate and long-continued observation the arterial blood-pressure is more conveniently studied by means of a U-shaped tube (a manometer) partially filled with mercury. One limb of the manometer is connected by means of a tube and a cannula with an artery (Fig. 157). For the purpose of retarding coagulation of the blood and for preventing the escape of a large volume of blood from the vessels, the system is filled with a solution of carbonate of soda of sp. gr. 1060, 5.58 grams per 1000 c.c., and under a pressure approximately equal to that in the vessel of the animal as determined in previous experiments. When communication is established between the vessel and the cannula, the mercurial column adjusts itself to the pressure in the artery and at once exhibits the same cardiac oscillations and respiratory undulations as did the column of blood in the previous experiment.

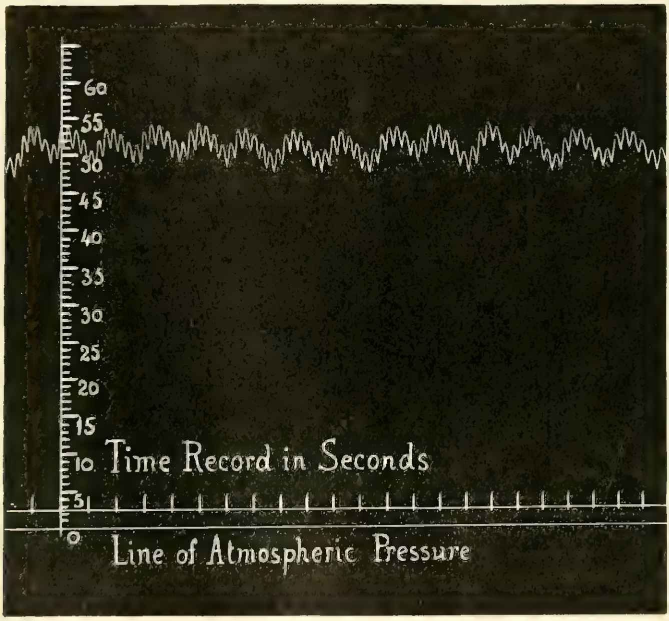

FIG. 158.—A PORTION OF A BLOOD-PRESSURE TRACING OBTAINED FROM THE CAROTID ARTERY OF THE RABBIT WITH A MERCURIAL MANOMETER. The small oscillations are due to the heart-beat, the large oscillations are due to the respiratory movements.

The height of the mercurial column kept in equilibrium by the pressure of the blood within, and the pressure of air without the vessel is that between the lower level of the mercury in the proximal, and the higher level in the distal limb of the manometer, both of which can be read off on a scale placed between the two limbs.

The height of the mercury as well as its oscillations in the distal limb may be recorded by placing on the top of the mercury a light float, the upper end of which carries a writing point. When the latter is placed in contact with the moving blackened surface of a recording cylinder or kymograph, the height and the oscillations are recorded in the form of a tracing similar to that shown in Figs. 157 and 158, in which the smaller oscillations represent the changes in pressure due to the systole and diastole of the heart and the larger oscillations to variations in the average pressure due to the respiratory movements. The height of the mercurial column kept in equilibrium at any particular moment is determined by measuring the distance between a base-line or abscissa, which represents the position of the mercury at atmospheric pressure, and any given point on the trace above, and multiplying it by 2, for the reason that the mercury sinks in the proximal limb as high as it rises in the distal limb of the manometer and hence the column of mercury supported is that observed between the upper and lower level of the mercury in the distal and proximal limbs of the manometer.

The blood-pressure as revealed by the tracing may be resolved into two components: viz., (1) a constant element and represented by the pressure in the arteries during the period of the cardiac diastole, which is termed the diastolic or minimum pressure; and (2) a variable element and represented by that additional pressure occurring at the time of the cardiac systole, which is termed the systolic or maximum pressure. The diastolic pressure is represented by the distance between the base-line and the points of the curve corresponding to the diastolic rest; the systolic pressure, by the distance between the base-line and the apices of the curves following the cardiac systole. The relation of these two components varies in different animals and in the same animal at different times. If the diastolic pressure is low, the systolic increase may be considerable; if the former is high, the latter may be slight. The relation, however, of these components is not so accurately shown by the mercurial manometer, owing to the inertia of the mercury, as by one of the various forms of quickly responsive spring manometers used in determining the rapid variations of intra-cardiac pressure. These instruments show a much larger rise of pressure during the systole, often amounting to as much as one-third or one-fourth of the diastolic pressure.

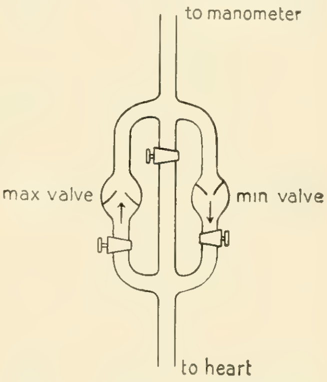

FIG. 159.—v. FRANK'S VALVE. This is placed in the course of the tube between heart and manometer, so that the latter may be used as a maximum, minimum, or ordinary manometer according to the tap which is left open.—(*Starling.*)

For the purpose of obtaining the maximum systolic and the minimum diastolic pressures, it is best, however, to insert between the cannula and the manometer a maximum and a minimum valve similar in principle to that shown in Fig. 159. By permitting the blood to exert its pressure first through the maximum valve and then permitting the mercurial column to exert its pressure through the minimum valve in the reverse direction for a certain length of time, or by permitting each to exert its pressure alternately with each heart-beat, the maximum systolic and the minimum diastolic pressures will be recorded. By this method Dawson found an average maximum pressure in the carotid artery of the dog of 162, and a minimum pressure of 103 mm. of mercury, a difference of 59 mm. Hg. The difference between these two pressures is known as the *pulse* pressure. (A diagram showing the relation of these different pressures one to another will be found on page 346.)

In a series of experiments it will be found that the blood-pressure in the arteries, though rising and falling a certain number of millimeters, yet retains a fairly constant general average, the result of an adjustment between the number of heart-beats per minute and the amount of the resistance offered to the escape of blood into the capillaries and veins. Between the two extremes there is, of course, a certain *average* or *mean* pressure which represents the power driving the blood through the vessels. It is frequently stated that in a tracing in which the respiratory undulations are absent, that the mean pressure is the arithmetic mean of the systolic and diastolic pressures. This is, however, not strictly correct, as can be demonstrated experimentally. Thus, if at some one point between the artery and the manometer, the lumen of the connecting tube be largely obliterated by a constriction, the variations in the pressure following the systole and diastole of the heart will be largely, if not entirely excluded, and the mercury, instead of rising rapidly in the manometer and fluctuating with each heart-beat, will rise slowly to a certain level and then remain at rest. The number of millimeters of mercury thus supported represents the *mean* or absolute pressure. The same result can be obtained by employing the compensatory manometer of Marey which presents a constriction of this character. From many experiments made by Dawson it has been learned that the mean pressure lies nearer to the diastolic than to the systolic pressure and may be expressed numerically by the statement that it is equal in millimeters of mercury to the diastolic pressure plus one-third of the pulse pressure. In a tracing in which the respiratory undulations are present the mean pressure can be calculated. The method by which this is done, however, is rather complicated and need not be detailed here. In a general way the mean pressure in such a tracing may be represented by a line drawn horizontally across the tracing midway between the apex and trough of the undulation.

Estimates of the Mean Arterial Pressure.—Because of the difficulty in obtaining the pressure in small arteries, the experimental determinations have for the most part been confined to large arteries such as the carotid, brachial and femoral, and hence the results which have been obtained have reference to the lateral pressure in the aorta or in the large vessels which immediately arise from it. The pressure obtained in the usual way at the central end of a divided carotid is generally known as the "end pressure" and represents the mean lateral pressure in the aorta or the innominate artery. Among the results thus obtained in different experiments from the carotid artery of different animals are the following: In the horse, from 122 to 214 mm. Hg.; in the dog, from 140 to 160 mm.; in the cat, 150 mm.; in the rabbit, from 90 to 100 mm.; in the sheep, 170 mm.; in the calf, from 133 to 165 mm. In two observations made on human beings previous to the amputation of a limb, the pressure was found in the brachial artery of one patient to vary from 110 mm. to 120 mm. Hg., and in the anterior tibial artery of the other patient from 110 mm. to 160 mm. Hg.

The investigations made in different parts of the arterial system indicate that the mean pressure is remarkably constant and uniform and does not show any noticeable falling off until near the arteriole region where the resistance suddenly and rapidly increases. Thus Volkman found simultaneously in the carotid artery and in the metatarsal artery of the sheep a mean pressure of 165 and 146 mm. Hg. respectively and this for the reason that the resistance throughout the arterial system does not markedly increase, until the arteriole region is reached. The careful investigations of Dawson show that in the large blood-vessels of the dog the diastolic pressure is as constant as the mean pressure though it undergoes slight variations in different regions; but that the systolic pressure, as shown by taking the end pressure in the thyroid and similar sized arteries in different parts of the arterial tree, undergoes a considerable falling off, though it, too, remains high in large arteries.

The numerical expressions of these various pressures in different parts of the arterial system are shown in the following table abstracted from the more extensive tables of Dawson. The results were obtained from experiments made on dogs. The figures represent in millimeters of mercury certain average end pressures in the arteries named.

Artery.	Systolic.	Mean.	Diastolic.	Pulse Pressure.
Brachio-cephalic	163	121	103	60
Right carotid	160	118	110	50
Left carotid	160	123	101	59
Left subclavian	168	123	105	63
Left brachial	160	118	110	50
Left renal	165	123	103	62
Deep femoral	152	118	102	50
Thyroid	140	118	97	43

The Capillary Pressure.—The small size of the capillaries precludes an investigation of their pressure by manometric methods. It may be stated, however, to be approximately equal to the pressure required to obliterate their lumen and to whiten the skin. The apparatus of v. Kries is based on this theory. A small glass plate, from 2.5 to 5 sq. mm., is fastened to the under surface of a support of suitable size carrying a small scale pan. The glass plate is placed on the skin near the root of a finger-nail and the scale pan gradually weighted until the vessels are obliterated, as shown by the blanching of the skin. From results obtained with this apparatus v. Kries estimated the pressure in the capillaries of the hand at 37 mm. Hg. and in the ear at 20 mm.

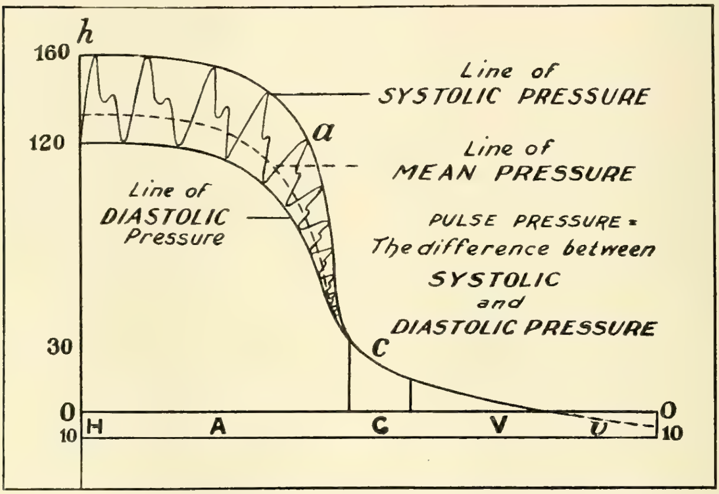

FIG. 160.—A DIAGRAM DESIGNED TO SHOW THE AMOUNT AND THE RELATION OF THE BLOOD-PRESSURE IN THE THREE DIVISIONS OF THE VASCULAR APPARATUS, AS WELL AS THE RELATION OF THE DIASTOLIC. The mean and the systolic pressures in the arterial system. Based on experiments made on dogs. H. Heart. A. Arteries. C. Capillaries. V. Large veins. O, O, being the zero line (= atmospheric pressure), the pressure is indicated by the height of the curve. The numbers on the left give the pressure (approximately) in millimeters of mercury. *h*. Pressure in heart. *a*. Arteriole region showing sudden fall of pressure. *c*. The fall of pressure in the capillaries. *v*. The negative pressure in the large veins.

The Venous Pressure.—In passing from the capillaries to the heart the pressure continues to fall. The increasing size of the veins permits again of manometric observations in different regions. In the crural vein the pressure has been found to be equal to 14 mm. Hg., and in the brachial vein 9 mm. of Hg. In the jugular and subclavian and other vessels near the heart it is zero or even *negative;* that is, less than atmospheric pressure to the extent of from 1 to 10 mm. of mercury.

The amount and relation of the different pressures in the three divisions of the systemic vascular apparatus are approximately shown in Fig. 160.

RESUME OF THE FACTS OF THE BLOOD-PRESSURE AND OF THE FACTORS WHICH CAUSE IT.

From a consideration of the foregoing facts and statements the following resumé may be made: 1. The blood during its flow exerts a pressure against the sides of the blood-vessels. 2. This pressure is the resultant on the one hand of the intra-ventricular pressure developed at the time of the contraction, and on the other hand of the resistance to the forward movement of the blood. 3. The resistance is to be sought for in the cohesion and friction of the molecules of the blood. 4. The resistance is proportional to the diameter of the vessel and is therefore least in the large arteries and veins and greatest in the arterioles and capillaries. 5. The pressure is highest in the aorta where it may amount in man to 150 mm. of mercury above that of the atmosphere, and lowest at the ends of the venæ cavæ where it may be no greater than that of the atmosphere or may be even 10 mm. Hg. below it. 6. The pressure falls from the beginning to the end of the vascular apparatus, though not progressively, for throughout the large vessels of the arterial system it continues relatively high. 7. The high pressure in the aorta is due to the total resistance of the vascular apparatus and the pressure at any given point of the apparatus represents the resistance yet to be overcome. 8. The high pressure in the arterial system and its marked fall at its periphery is more especially the result of the very great resistance at this point, known as the *peripheral resistance*, the result of a rapid diminution in the diameter of the arterioles and the capillary vessels, modified by the tonic contraction of the arteriole muscles. 9. The pressure in the arterial system undergoes considerable variation both above and below the mean pressure during the systole and diastole of the heart.

The Heart.—The primary factor in the production of the pressure is the pumping action of the heart. Should there be any cessation in its activity, the elastic walls of the arteries would recoil and force the blood into the veins. There would be coincidently a fall of pressure equal to that of the atmosphere. Even under normal circumstances this condition is approximated during the diastole. The recoil of the arterial wall by which the forward movement of the blood is maintained is attended by a fall in pressure. But before this reaches any considerable extent, the heart again contracts and forces its contained volume of blood into the arteries.

That this may be accomplished it is essential that the cardiac energy be sufficient not only to drive a portion of the blood through the capillaries into the veins, but to oppose the recoiling arteries, and to distend them to their previous extent, so that the incoming volume of blood may be accommodated. This at once reestablishes the pressure at its former level.

During the contraction of the heart the kinetic energy is transformed into potential energy, represented by the tense distended walls of the arteries. With the relaxation of the heart and the closure of the semilunar valves the potential energy of the arteries is again transformed into kinetic energy, represented by the moving blood. The artery thus continues the work of the heart during its period of inactivity. The rapidity with which the cardiac contractions succeed each other prevents the pressure from sinking below a certain average level.

The Resistance.—The secondary factor is the resistance to the flow of blood through the vessels, the nature of which has been previously stated. So long as the resistance, and especially that variable element of it at the periphery of the arterial system, maintains a certain average value, so long will the pressure in each division of the vascular apparatus maintain an average or a physiologic value. Should the resistance at the periphery of the arterial system vary in either direction, the result of an increase or a decrease in the degree of the contraction of the arteriole muscle, there will arise a change in the relative degree of pressure in each of the three divisions of the vascular apparatus.

The Elasticity of the Vessel Walls.—A tertiary factor is the elasticity of the arterial wall. While it can hardly be said that the elasticity is a cause of the pressure, there can be attributed to it the capability of modifying and assisting in the maintenance of the pressure at a more or less constant level; for were it not for this property of the vessel wall the variations in pressure during and after the systole would be far more extensive than they are, and would approximate the variations observed in tubes with rigid walls. The elasticity, moreover, assists in the equalization of the blood-stream, converting the intermittent and remittent flow characteristic of the large arteries into the continuous equable stream characteristic of the capillaries. It also permits of wide variations in the amount of blood the arteries can contain between their minimum and maximum distention.

VARIATIONS IN THE BLOOD-PRESSURE.

A. In the Arterial Pressure.—It is evident from the preceding statements that the arterial blood-pressure as a whole may be increased by:

1. An *increase* in the rate or force of the heart's contraction.
2. An *increase* in the peripheral resistance.
3. An *increase* in both the force of the heart and the peripheral resistance.

And that it may be decreased by:

1. A *decrease* in the rate and force of the heart's contraction.
2. A *decrease* in the peripheral resistance.
3. A *decrease* in both the force of the heart and the peripheral resistance.

If when the arterial pressure is in a condition of equilibrium the heart ejects into the arteries in a given period of time an increased quantity of blood as a result of an increased rate of contraction, there will be an accumulation of blood temporarily in the arteries and a rise of pressure (the peripheral resistance remaining the same), for the reason that the pressure is only sufficient to force into the capillaries a given volume, in the same period of time. As the pressure rises the velocity and the outflow will be increased until equilibrium is restored though at a somewhat higher level. A rise of pressure from an increase in the rate of the beat alone has been questioned, for it has apparently been demonstrated that there is a definite relation between the normal rate and the volume discharged from the ventricle, and that when the rate is increased, the volume discharged diminishes and hence the pressure remains normal or even falls below the normal.

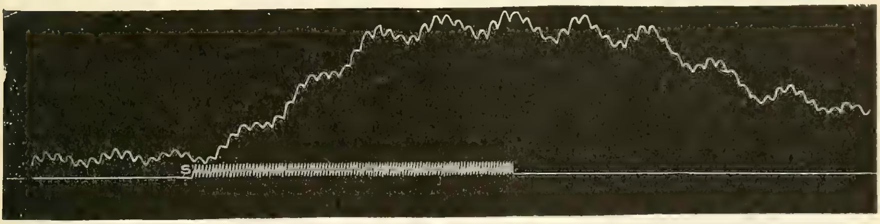

FIG. 161.—A TRACING SHOWING AN INCREASE IN THE BLOOD-PRESSURE IN THE CAROTID ARTERY OF A RABBIT DUE TO AN INCREASE IN THE PERIPHERAL RESISTANCE FROM A CONTRACTION OF THE ARTERIOLES CAUSED BY REFLEX STIMULATION OF THE VASO-MOTOR CENTER. The nerve stimulated was the sciatic. Stimulation began at s. The rate of the heart-beat is unchanged. With the cessation of the stimulation the blood-pressure falls for the reverse reasons.

An increase in the pressure is readily brought about by an increase in the force or power of the contraction, the frequency remaining the same. An increase in the volume of blood ejected at each contraction will necessarily lead to an accumulation. With the accumulation there goes an increased distention of the artery and a corresponding increase of pressure. In a short time, therefore, the increased pressure will force out of the arteries at a higher rate of speed this excess of blood until the outflow again equals the inflow. This restores the equilibrium but establishes the mean pressure at a higher level.

If the peripheral resistance is increased by a contraction of the muscle walls of the arterioles, the frequency and force of the heart remaining the same, there will also be an accumulation of blood in the arteries, an increased distention and consequent rise of pressure (Fig. 161). The outflow of blood will at the same time be diminished. A rise of pressure from this cause much beyond the normal is to a large extent prevented by a simultaneous decrease in the rate and force of the heart-beat. This is due to a stimulation of the peripheral ends of the depressor nerve, and a consequent reflex stimulation of the cardio-inhibitor center, and not to a direct action on the heart-muscle, inasmuch as the effect is not observed after division of the vagi. When both the force of the heart and the peripheral resistance are simultaneously increased there is a rapid increase in pressure; the former factor tends to increase, the latter factor, to decrease, the velocity of the outflow. According as the one or the other preponderates, will there be an increase or decrease in velocity. If they balance each other, there will be no change. A rise of pressure from a combination of these factors is rather a pathologic than a physiologic condition and is observed in certain diseases of the vascular apparatus.

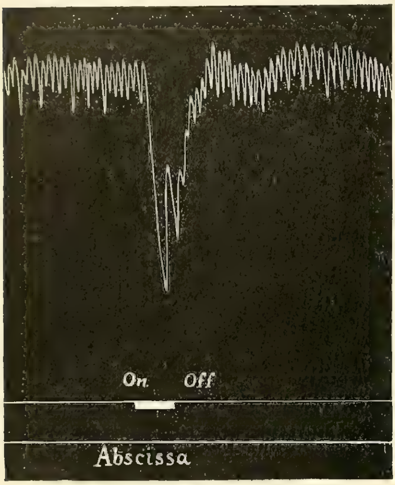

FIG. 162.—A TRACING OF THE BLOOD-PRESSURE IN THE CAROTID ARTERY OF A RABBIT, showing a sudden decrease in the pressure due to an arrest in the rate and force of the heart-beat the result of stimulating the vagus nerve from "on" to "off." With the cessation of the stimulation the pressure began to rise as the rate and the force of the heart-beat returned. (The abscissa should be 20 mm. lower.)

The converse of these statements also holds true. If when the general arterial pressure is in a condition of equilibrium the heart ejects into the arteries in a given period of time a lessened quantity of blood, either as a result of a decrease in the rate or force, there will soon be a diminution of the arterial distention and a consequent fall in pressure (Fig. 162). The velocity at the same time diminishes. This continues until the outflow no longer exceeds the inflow. Equilibrium will again be established, but the pressure will be at a lower level.

If the peripheral resistance is diminished by a dilatation of the arterioles, the heart's contractions remaining the same, the existing pressure soon diminishes. The outflow of blood at once increases in velocity.

As a rule a diminution in peripheral resistance is attended by an increase in the rate or force of the heart, and this is especially the case if the pressure has been above the normal.

When both the force of the heart and the peripheral resistance are simultaneously diminished, there will be a rapid fall in pressure. The former factor tends to decrease, the latter factor to increase the velocity of outflow. According as the one or the other preponderates will there be a decrease or an increase in velocity. If they balance each other there will be no change. This condition is also a pathologic rather than a physiologic condition and observed in states of profound depression due to serious injuries.

Local Variations in the Arterial Blood-supply.—The variations in pressure and velocity from variations either in the activity of the heart or in the peripheral resistance recorded in preceding paragraphs, have reference to the arterial system in its entirety; but it is evident from many facts that similar variations take place in special regions or organs of the body. Thus, it is a well-known fact that for the exhibition of the functional activity of every organ there must be an increase in the volume of blood supplied to it in each unit of time. This is accomplished by an active dilatation of the arterioles of the artery of supply, and unless the area or organ supplied is large, as the splanchnic area for example, there will be no necessary diminution in either the general blood-pressure or the average velocity. With the cessation of functional activity, there is no longer any need for so large a blood-supply and hence the arterioles contract, diminish the outflow, and raise the pressure. If, on the other hand, the area to be supplied be large, as the splanchnic area, the dilatation of the intestinal arteries will be attended by such a large inflow of blood that not only will there be a fall of pressure in these vessels, but a fall of pressure in other arteries as well, combined with a diminution in velocity through them. With the contraction of the intestinal arteries the reverse conditions at once arise. By constant variations in the peripheral resistance of individual arteries in each and every region of the body, and in association with variations in the rate or force of the heart, the blood is shunted now into this, now into that organ in accordance with its functional needs. All variations in peripheral resistance are largely brought about reflexly by the vaso-motor nerves, the origin, distribution and mode of action of which will be considered in subsequent paragraphs.

B. In Capillary Pressure.—The pressure in the capillaries, though for the most part possessing a permanent value, is subject to variations in accordance with variations in the pressure in either the arterial or venous systems or both. The marked difference in the pressure in the large arteries and the capillaries is partly due to the resistance offered by the narrow arterioles. If the latter dilate in any given area, the capillary pressure increases because of the propagation into them of the arterial pressure. The reverse condition would decrease the pressure. On the other hand, any interference with the outflow from any given area, due to venous compression, would likewise increase the pressure; any factor which would, on the contrary, favor the outflow would decrease the pressure. Independent of any change in the arteriole resistance, it is evident that a rise in arterial pressure alone would increase the capillary pressure. If both arterial and venous pressures rise, the capillary pressure increases; if both fall, it decreases.

C. In Venous Pressure.—Independent of any change in the venous pressure in a given area from local or temporarily acting causes—*e. g.*, aspiration of the thorax or heart, muscle contractions, change of position, etc.—the general venous pressure will be *increased* by a decrease in the value of those factors which produce the difference of pressure between the arteries and veins. An increase in the value of these factors would necessarily *decrease* the pressure.

Variations in the Relation of the Arterial and Venous Pressures.—So long as the heart maintains a given rate and force and the resistance at the periphery of the arterial system (due to the contraction of the arteriole muscle) a given value, will the usual physiologic difference between the pressure in the arteries and veins remain unchanged. If, however, either factor changes in one direction or another, there will arise a change in the relative degree of pressure in the different divisions of the vascular apparatus. Thus if the heart force increases and a larger volume of blood is discharged into the arteries in a unit of time, the amount of blood in the venous system diminishes, and the result is a rise of the arterial and a fall of the venous pressures. If, on the contrary, the heart force decreases or the mitral valve permits of a regurgitation, a smaller volume of blood is ejected into the arteries in a unit of time, the amount of blood in the venous system increases, and the result is a fall of the arterial and a rise of the venous pressure.

Again if the arteriole muscle relaxes and a larger volume of blood flows from the arteries into the veins in a unit of time, the result will be a fall of arterial and a rise of venous pressure. If, on the contrary, the arterial muscle contracts and a smaller volume of blood flows into the veins, the reverse change of pressure obtains.

The Determination of the Arterial Blood-pressure in Man.—Inasmuch as the blood-pressure undergoes considerable variation in both physiologic and pathologic conditions as well as in response to the action of drugs, it seemed desirable to possess some means by which an accurate knowledge of the pressure under a variety of conditions could be obtained both for diagnostic and therapeutic purposes. The foregoing method of obtaining the blood-pressure not being of general application to human beings for obvious reasons, special instruments have been devised by which the pressures may be determined at least approximately without resorting to any surgical procedure. These instruments are turned *sphygmomanometers*. Some of the many forms of this instrument are adapted for obtaining the systolic pressure only, while others are adapted for obtaining either the systolic or the diastolic pressure, or both.

The principle involved in the first group is the application of an elastic pressure to an artery, *e. g.*, the temporal, radial, etc., until the lumen is completely obliterated as indicated by the disappearance of the pulse beyond the point of compression, and at the same time register the pressure applied, by means of a mercurial or spring manometer. The pressure just sufficient to obliterate the pulse or to allow it to reappear after obliteration, is taken as the systolic pressure.

The principle involved in the second group is based on a suggestion of Marey, that the maximum pulsation of the artery or the maximum distention and recoil following a heart-beat would be most likely to take place when an elastic pressure applied to the outside of an artery is just sufficient to equalize the diastolic pressure within. Inasmuch as these pulsations can be transmitted to, taken up and reproduced by a mercurial column in connection with the pressure appliances, it becomes possible, when the maximum oscillation of the mercurial column is attained, to read off the diastolic pressure.

With either form of apparatus it became necessary to devise a suitable elastic sac or tube enclosed by non-elastic or rigid walls and which could be made to encircle a finger or an arm, and which could in turn be connected with a pressure apparatus, and with a manometer by which any given pressure could be registered.

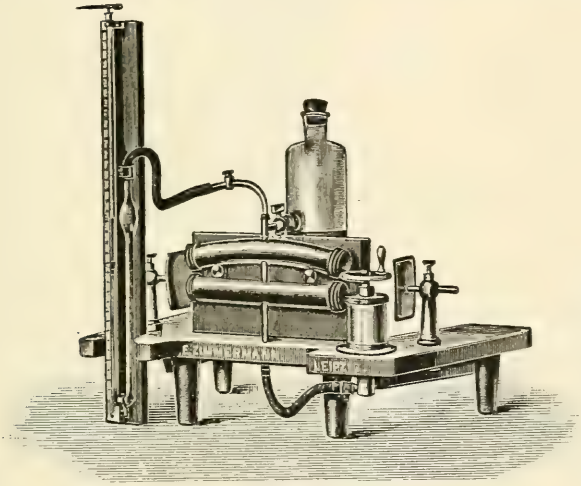

FIG. 163.—THE SPHYGMOMANOMETER OF MOSSO.

One of the best known of the sphygmomanometers in that of Mosso represented in Fig. 163. It consists essentially of rubber capsules, contained within metallic tubes and into which two fingers of each hand can be inserted. This system is connected, on the one hand, with a pressure apparatus, and, on the other, with a manometer provided with a scale. A float and writing-pen record the movements of the mercurial column on a moving blackened surface. In using this apparatus the pressure is adjusted to the point at which the mercurial column exhibits the greatest oscillations.

Mosso's interpretation of the results obtained with this apparatus was that when the greatest oscillations of the mercurial column were taking place, the external pressure was just equal to the *mean* arterial pressure, the latter being the mean between the maximum pressure during the systole and the minimum pressure during the diastole of the heart. It was only necessary, therefore, to take the readings corresponding to the excursions of the mercurial column and to determine from them the mean arterial pressure.

It has been experimentally demonstrated, however, by Howell and Brush that this interpretation, either for this or any similar form of apparatus, is not correct, but that the maximum oscillations take place when the pressure applied to the exterior of the artery is just equal to the pressure within the artery at the end of the cardiac diastole; or in other words, the pressure in the manometer from which the greatest oscillation takes place indicates diastolic pressure. These experimenters connected the right carotid artery of a dog with a mercurial manometer, interposing along the course of the connecting tube a maximum and a minimum valve. The left carotid artery was surrounded by a plethysmograph which was connected, on the one hand, with both a mercurial and a spring manometer, the former for the purpose of indicating the pressure necessary to obtain the greatest oscillation, the latter for the purpose of magnifying and recording the pulsation. When the observations were simultaneously made it was found that the diastolic pressure in the right carotid measured by the minimum manometer was almost exactly equal to the pressure measured by the manometer in connection with the sphygmomanometer surrounding the left carotid artery, when it was exhibiting its maximum excursions. The difference in the results of the two sides scarcely exceeded more than one or two millimeters of mercury. It was, therefore, established that the greatest oscillations record diastolic pressure. It was also shown by the same investigators that Mosso's apparatus is not adapted for obtaining systolic pressure.

Among the many forms of sphygmomanometers adapted for clinic purposes and with which both systolic and diastolic pressures may be obtained is that devised by Stanton* (Fig. 164). The pressure is applied to the arm by the rubber armlet H, which is 3¼ inches wide. This is the widest armlet that can be adjusted to the average-sized arm and presents distinct advantages over the narrow armlet hitherto employed. This armlet is prevented from expanding outward by a cuff, F, of double thick canvas with inserted strips of tin, which is held in place by two straps which completely encircle the cuff. On the rigidity of this depends to a large extent the transmission of pulsation. The rubber armlet is connected by glass with a stiff-walled rubber tube, G, which in turn connects with the manometer. The manometer is perhaps the most important part of the apparatus. It is constructed entirely of metal except for the glass tube containing the mercury column. The chamber C communicates by means of a metal tube with the glass column D, which is connected by a screw-thread at 3, the caliber of C being approximately 100 times that of D.

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*The following description of this apparatus is abstracted from the Univ. of Pa. Medical Bulletin, Feb., 1903.

The cap of the chamber, which screws on, is provided with a metal T which is connected at 2 with the rubber armlet and at 1 with the bulb, used as an air-pump. At A is a stopcock shutting the rubber bulb completely from the rest of the apparatus while at B is a screw-valve which allows the air to escape from the closed system. When desired, the manometer can be made portable (without removing the mercury) by screwing the caps 1 and 2 into either end of the T at 1 and 2. The manometer is then tilted away from the glass column D until all the mercury has run into the chamber, the glass is then unscrewed and cap 3 screwed in. Before removing cap 3 the manometer must always be tilted, else the mercury will be lost.

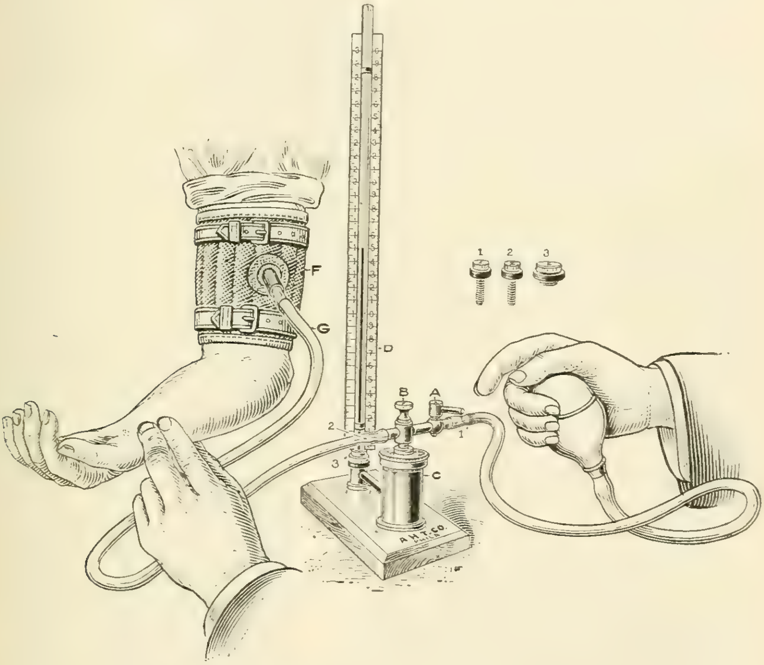

FIG. 164.—STANTON'S SPHYGMOMANOMETER.

The rubber bulb is similar to those found on atomizers.

In using this apparatus the pressure is raised by the air-bulb forcing air into the closed system—distending the rubber armlet and with the same degree of force displacing the mercury in C, driving it up the glass column D. When the pulse is no longer felt, the bulb still being compressed, the arm of valve A is turned until it is at right angles with the thumb and finger. The valve B is now slowly unscrewed until the mercury column begins to fall. With the eye on the scale the point at which the pulse reappears is mentally noted as the systolic pressure. Often considerably before the reappearance of the pulse to palpation, a pulsation is seen in the mercury column. As the column slowly falls this increases up to its greatest oscillation and then diminishes. The lowest point of the greatest pulsation is noted as the diastolic pressure.

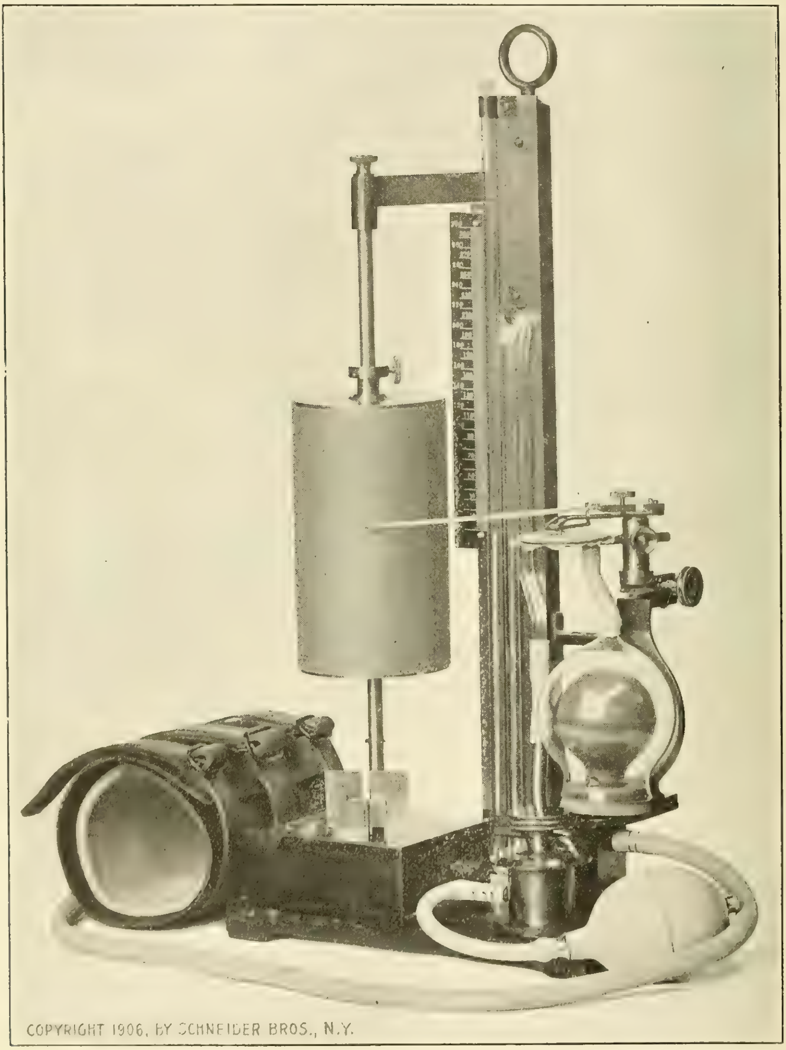

FIG. 165.—ERLANGER'S SPHYGMOMANOMETER.

Erlanger's sphygmomanometer is, also, a most valuable instrument for obtaining both systolic and diastolic pressure. It possesses an advantage in that it is provided, in addition to the mercurial manometer, with a tambour and lever by which the changes in pressure can also be recorded on a revolving cylinder (Fig. 165). A complete description of this apparatus, the manner of using it and the results that can be obtained with it will be found in the Johns Hopkins Hospital Reports, Vol. XII.

Any statement as to the numerical values of the different pressures is somewhat difficult to make inasmuch as they will vary within physiological limits in accordance with the position of the body, exercise, character of psychic states, digestion, temperature and other conditions. For comparative investigations it is necessary, therefore, to place the subject of the investigation in one and the same position, to apply the cuff to the corresponding arm, to use always a uniform width of cuff and to select the same time of day with reference to meals, etc.

It may be stated, however, that in adult life the systolic pressure in the brachial artery ranges from 110 to 135 millimeters of Hg. in men and about 10 mm. less in women; the diastolic pressure ranges from 65 to 110 mm. Hg.; the pulse pressure ranges from 25 to 40 mm. Hg.

The conclusions of Erlanger regarding the results of his investigations with this apparatus may be partially summed up in the following statements, and as they hold true for other forms of apparatus which determine both systolic and diastolic pressures, they are here appended: "The pressure that is determined by occluding an artery is probably the maximum end pressure of the artery occluded. The pressure determined by the method of maximal oscillations is the minimum lateral pressure of the artery compressed, and, therefore, as the minimum lateral pressure is the same in all of the larger arteries, the *pulse pressure*, determined when the pressures in the brachial artery are observed, tends to approximate the lateral *pulse pressure* in the aorta."

THE VELOCITY OF THE BLOOD.

From the number of heart-beats per minute, 72, and the amount of blood discharged from the left ventricle at each beat, 180 c.c., it is evident that the blood must be flowing through the vascular apparatus with a certain velocity, for during the minute the entire volume of blood, 5769 grams, must have passed twice through the heart. Direct observation of the escape of blood from the central end of a divided artery, and from the peripheral end of a divided vein, as well as of the flow through the capillaries as seen with the microscope, shows that the velocity of the flow varies in different parts of the vascular apparatus. In the arteries, moreover, the flow is not quite uniform, but experiences alternate acceleration and retardation with each heart-beat. In the capillaries and veins the flow is continuous and uniform, as the conditions of the arterial walls are such as to completely overcome the intermittency.

If the systemic vascular apparatus be conceived of as a system of tubes which have symmetrically divided and subdivided, and have again united and reunited in a corresponding manner, it is clear that the total sectional area will steadily increase from the beginning to the middle of the system, and then as steadily decrease from the middle to the end of the system. In such a system the same volume of blood must pass through any given section in a unit of time if the balance of the circulation is to be maintained. As the velocity of a fluid is inversely as the sectional area of the tubes through which it flows, it follows that the initial mean velocity of the blood in the aorta will steadily decrease as it flows into the steadily enlarging stream-bed until it reaches a minimal value in the middle of the capillary system; and that it will again steadily increase as it flows into the narrowing stream-bed until it reaches the heart. The initial mean velocity of the blood in the aorta will not be attained in the venæ cavæ, for the reason that the total sectional area of the latter is somewhat greater than that of the former. The same facts hold true for the pulmonic vascular system.

The Mean Velocity in the Aorta.—From the well-known fact that the velocity with which a fluid is flowing through a tube may be determined by dividing its sectional area into the quantity discharged in a unit of time, attempts have been made to determine the mean velocity of the blood at the beginning of the aorta. If it be assumed that the volume discharged at each contraction is 180 c.c., as stated by Vierordt, and the number of heart-beats per minute at 72, the total volume discharged per minute would be 12,960 c.c., or 215 c.c. per second. The sectional area of the aorta at its origin is 6.15 sq. cm. On the principle above stated, these two factors would show a velocity of 350 mm. per second. An objection to this estimate is that the amount of blood discharged—*i. e.*, the contraction volume—is much larger than recent investigations warrant. Different observers have estimated that in man the contraction volume is considerably less, probably not more than 80 c.c.

The Mean Velocity in the Arteries.—The mean velocity of the blood in the larger and more superficially lying arteries has been determined by Volkmann with the hemodromometer, by Ludwig and Dogiel with the stromuhr, and by other investigators with different forms of apparatus.

Since neither the blood nor any particle placed in it can be seen through the walls of the artery, it occurred to Volkmann to intercalate along the course of a vessel a U-shaped glass tube about one meter in length with a lumen the diameter of that of the selected vessel, into and through which the blood could be made to flow. The mechanic construction of the apparatus is such (Fig. 166) that the blood can be made to flow directly into the distal portion of the artery across the base or indirectly by way of the glass tube. Previous to the intercalation of the tube it is filled with serum or normal saline solution. With the turning of the cocks at B the blood enters the glass tube and drives the serum ahead of it into the arterial system. From the difference in time between the moment the blood enters and the moment it leaves the tube and from the length of the tube the velocity is determined.

The stromuhr or rheometer of Ludwig (Fig. 167) is constructed on the same principle, but instead of the glass tube having the same diameter it is considerably enlarged on its two sides. The bulbs are fastened to a metallic disk which rotates around an axis in the metallic base which carries the tubes to be inserted into the arteries.

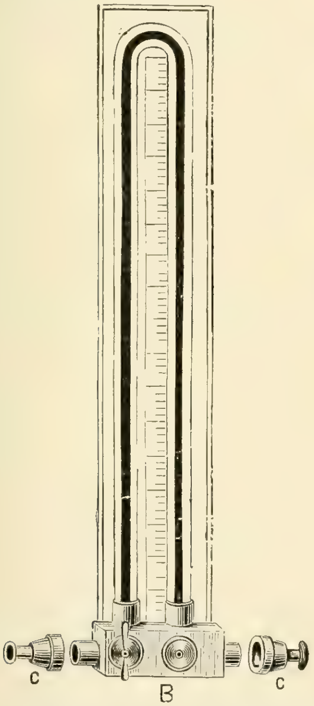

FIG. 166.—VOLKMANN'S HEMODROMOMETER. C, C. Arterial cannulas,

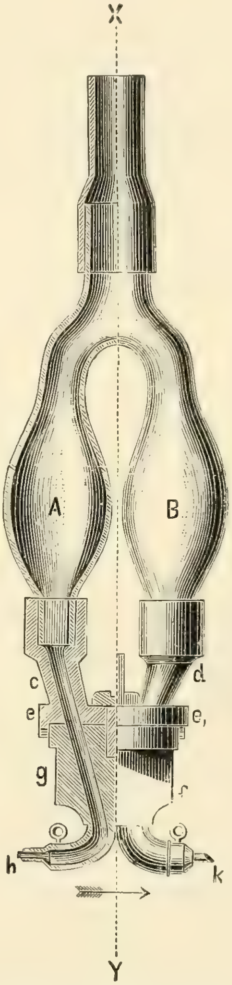

FIG. 167.—LUDWIG AND DOGIEL'S RHEOMETER. X, Y. Axis of rotation. A, B. Glass bulbs. *h*, *k*. Cannulas inserted in the divided artery. *e*, e_1, rotates on *g*, *f*. *c*, *d*. Tubes.

With this device it is possible to place either bulb in connection with the proximal end of the artery. Previous to the experiment the proximal bulb is filled with oil, the distal bulb with serum or normal saline. On removing the clips on the artery the blood flows into the proximal bulb and drives the oil into the distal bulb. As soon as the former is filled with blood the bulbs are reversed and the same relative conditions are attained. This is repeated a number of times. Knowing the capacity of the bulbs, and the number of times they are filled in a given period, the total quantity of blood discharged is obtained. This divided by the sectional area of the artery gives the velocity. The following values have thus been obtained: For the carotid of the dog, 205 to 357 mm. per second; for the carotid of the horse, 306 mm.; for the metatarsal artery of the horse, 56 mm. (Volkmann). For the carotid of rabbits, 94 to 226 mm.; for the carotid of the dog, 349 to 733 mm. (Dogiel).

The *variations* in the velocity of the blood in the arteries during the different phases of the cardiac cycle have been determined by Chauveau and Lortet with the hematachometer (Fig. 168). This consists of a metallic tube carrying a graduated disk. At one point the tube is perforated but covered with a rubber band through which passes an index. When the tube is inserted into the divided ends of an artery, the current of blood strikes the short arm of the index and gives to the outer long arm a movement in the opposite direction. The extent of the excursion indicates the velocity. The apparatus is first graduated with currents of water of known velocity. With this instrument Chauveau found that in the horse the velocity during the systole was 520 mm. per second, at the beginning of the diastole 220 mm. per second, and during the pause 150 mm. per second.

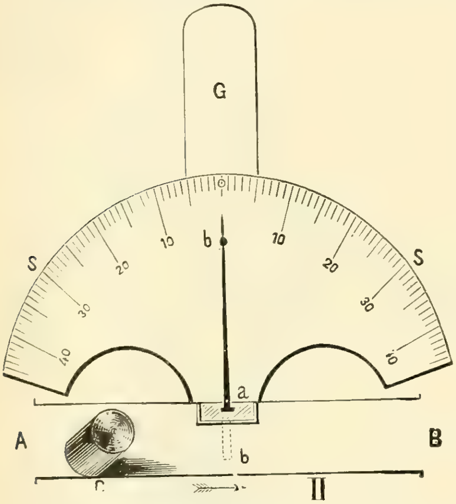

FIG. 168.—THE HEMATACHOMETER OF CHAUVEAU AND LORTET. A, B. Tube inserted in artery. C. Lateral tube connected with a manometer. *b*. Index moving in a caoutchouc membrane, *a*. G. Handle.

The Velocity in the Capillaries.—The rate of flow in the capillary vessels can not be experimentally determined. It has been estimated by Vierordt at 0.5 mm. per second in his own retinal capillaries; by Weber at 0.8 mm. In frogs the velocity can be fairly well determined by observing the time required for a corpuscle to pass over one or more divisions of an ocular micrometer. Weber calculated in this way that the velocity is 0.5 mm. per second.

As the velocity varies inversely with the sectional area, it becomes possible to approximately determine the relation of the sectional area of the capillary system to that of the aorta from the above-mentioned velocities. If it be assumed that the velocity in the aorta averages 300 mm. and in the capillaries 0.5 mm. per second, then the sectional area of the capillaries is to that of the aorta as 600 to 1.

The Velocity in the Veins.—In the venous system the velocity increases in proportion as the sectional area decreases. In the jugular vein Volkmann found the velocity 225 mm. per second, which was about one-half that in the aorta of the same animal. The reason for the slow rate of movement in the jugular vein is to be found in the fact that the sectional area of the combined venæ cavæ is about twice that of the aorta; hence the relation of the sectional area of the capillary system to the sectional area of the venæ cavæ is about 300 to 1.

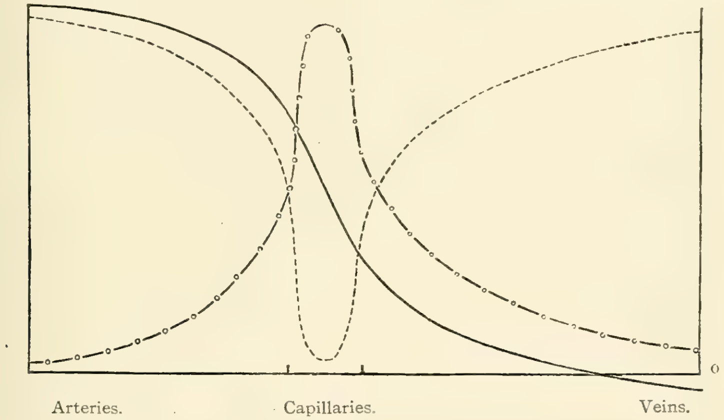

Fig. 169.— ———, Blood-pressure. ------, Velocity. —o—o—o—o, Sectional area.

The blood-pressure, the velocity of the blood, the sectional area of the vascular apparatus, and their relation one to the other are shown in Fig. 169.

The Relations of Blood-pressure and Velocity.—Though the pressure of the blood bears a definite relation to the velocity it must be kept in mind that it is rather the *difference in pressure* between the beginning and the termination of the arterial system, rather than the *mean* pressure that influences the velocity. Thus, with a given force of the heart and a given peripheral resistance, the velocity will have a given value, and so long as these factors remain constant will the velocity remain constant, even though the mean pressure should fall, as from a hemorrhage, or should rise, as from an injection of some indifferent fluid.

If, however, the primary factors, viz., the cardiac force or the peripheral resistance, change their values in either the same or opposite directions, there will be a change at once in the velocity. The variations in pressure and velocity, both in the same and opposite directions, which are theoretically possible from a change in the force of the heart, or in the peripheral resistance, or both, are shown in the following table arranged by Waller. The plus sign indicates increase, the minus sign, decrease, in effect.

No.	Heart	Arterioles	Blood-pressure	Blood-flow
1	Force constant	Resistance increased	+	—
2	Force constant	Resistance diminished	—	+
3	Force increased	Resistance constant	+	+
4	Force diminished	Resistance constant	—	—
5	*Force increased*	*Resistance diminished*	+ —	+ +
6	*Force diminished*	*Resistance increased*	— +	— —
7	Force increased	Resistance increased	+ +	+ —
8	Force diminished	Resistance diminished	— —	— +

The statements herein embodied have been established by Marey with an artificial schema of the circulatory apparatus, and by Chauveau and Lortet by experiments on animals with the hemodromograph, a specially devised apparatus for this purpose.

Though all the relations between pressure and velocity in the table are possible, those which are most physiological are probably 5 and 6, for in both instances there is a minimum alteration in pressure, but a maximum alteration in blood flow or velocity. The first instance is the condition most favorable for the functional activity of organs, for the reason that the volume of blood which the organ receives in a unit of time is increased without any change in pressure; and it is an established fact that within physiological limits it is the volume of blood which an organ receives rather than the pressure under which it is received, that determines its activity. In the second instance, on the cessation of activity the velocity is decreased and the normal condition restored without any appreciable change in pressure.

THE PULSE.

The pulse may be defined as a periodic expansion and recoil of the arterial system. The expansion is caused by the discharge from the heart into the arteries of a volume of blood during the systole; the recoil is due to the elastic reaction of the arterial walls on the blood, driving it forward, into, and through the capillaries, during the diastole.

At the close of the cardiac diastole the arterial system is full of blood and considerably distended. During the occurrence of the succeeding systole, a definite volume of blood is again discharged into the aorta. The incoming volume of blood is now accommodated by the discharge of a portion of the general blood volume into the capillaries and by the expansion of the arteries. The expansion naturally begins at the root of the aorta and at the beginning of the systole. As the blood continues to be discharged from the heart, adjoining segments of the aorta and its branches expand in quick succession, and by the time the systole is completed the expansion has traveled over the entire arterial system as far as the capillaries. With the cessation of the systole and perhaps even before, the recoil of the arterial walls at once occurs, beginning at the root of the aorta and rapidly passing over the arteries to the capillaries.

This expansion movement which thus passes from the beginning to the end of the arterial system in the form of a wave is known as the *pulse-wave* or *pulse.* Preceding and causing the expansion and recoil of the arterial system there is an alternate increase and decrease of the general blood-pressure, as shown by the small curves on a blood-pressure tracing, and for this reason the pressure which causes the expansion and recoil is termed the *pulse pressure.* It is defined as the rhythmic change in pressure at any given point of the arterial system; and in amount, is the difference between the diastolic and the systolic pressures, at the corresponding points. The volume of blood ejected from the ventricle is frequently termed the *pulse volume.*

The pulse-wave which thus spreads itself over the entire arterial system with each systole of the heart can be perceived in certain localities by the eye, by the sense of touch, and investigated with various forms of apparatus or instrumental means. The pulse-wave, or at least the elevation of the soft tissues overlying it, can be seen in the radial artery, where it passes across the wrist-joint, in the carotid artery, in the temporal artery, in the arteries of the retina under certain conditions, with the ophthalmoscope. If the ends of the fingers are firmly placed over the radial artery, not only the increase and decrease of pressure, but also many of the peculiarities of the pulse-wave, may be perceived. Without much difficulty it may be perceived that the expansion takes place quickly, the recoil relatively slowly; that the waves succeed one another with a certain frequency, corresponding to the heart-beat; that the pulsations are rhythmic in character, etc. Inasmuch as the individuality of the pulse-wave varies at different periods of life and under different physiologic and pathologic conditions, various terms more or less expressive, have been suggested for its varying peculiarities. Thus the pulse is said to be *frequent* or *infrequent* according as it exceeds or falls short of a certain average number—72 per minute; *quick* or *slow,* according to the suddenness with which the expansion takes place or strikes the fingers; *hard* or *soft, tense* or *easily compressible,* according to the resistance which the vessel offers to its compression by the fingers; *large, full,* or *small,* according to the volume of blood ejected into the aorta, or, in other words, the degree of fullness of the arterial system.

Frequency of the Pulse.—As the pulse or the arterial expansion and recoil is the direct result of the heart's action, its frequency must, under physiologic conditions, coincide with that of the heart. All conditions which modify the rate of the heart will modify at the same time the rate of the pulse.

The Velocity of Propagation of the Pulse-wave.—The propagation of the pulse-wave from its origin at the root of the aorta to any given point of the arterial system occupies an appreciable period of time. The difference in time between the systole and the appearance of the pulse-wave at the dorsal artery of the foot can be appreciated by the sense of touch. The absolute time occupied by the wave in reaching this point was determined by Czermak to be 0.193 second. The rate at which the wave is propagated over the vessels of the lower extremity has been estimated by the same observer at 11.16 meters per second, and for the upper extremities at but 6.7 meters per second. Other experimenters have obtained for the lower extremities somewhat different results, varying from 6.5 to 11 meters per second. Weber's original estimate was from 7.92 to 9.24 meters per second. The slower rate of movement in the vessels of the upper extremities has been attributed to a greater distensibility of their walls, a condition unfavorable to rapid propagation. For this reason a low arterial tension will occasion a delay in the appearance of the pulse-wave in any portion of the body; a high arterial tension will of course have the opposite effect. The difference in the speed of the pulse-wave and the blood-current shows that they are not identical and must not be confounded with each other.

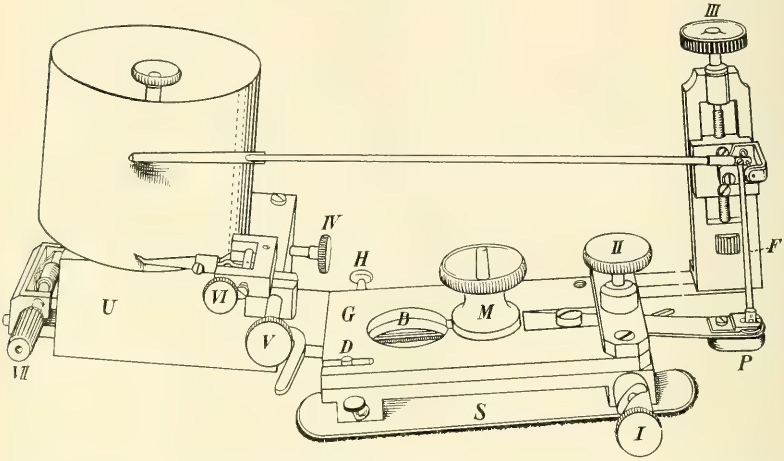

FIG. 170.—VON FREY'S SPHYGMOGRAPH. *G. S.* Metal framework. *P.* Button attached to spring. *F.* Vertical rod. *U.* Clock-work which turns the recording cylinder. *VI.* Time marker.

The Sphygmograph.—The sphygmograph is an apparatus designed to take up, reproduce, and record the alternate expansion and recoil of an artery caused by the temporary increase and decrease of pressure following each heart-beat. The tracing or record obtained with it is termed the pulse-curve or the *sphygmogram.* Different forms of this apparatus have been devised by Marey, Dudgeon, v. Frey, and many others. The instrument of v. Frey is shown in Fig. 170. This consists first of a metal framework by which the apparatus is fastened to the arm and support given to the lever, recording surface, etc. The essential part is the spring carrying a button which is placed over the artery, usually the radial, before it crosses the wrist-joint. A vertical rod transmits the movement of the spring to the recording lever; the movements of the latter are recorded on a small cylinder inclined slightly so that the upstroke may be vertical. A small electro-magnet serves to record the time relations of the changes in the blood-pressure. An average tracing taken from the radial artery is shown in Fig. 171. This, however, is not a tracing of the pulse-wave, but rather a record of the changes in pressure, their succession and time relations, which follow each beat of the heart. The artery usually selected for obtaining a sphygmogram is the radial. This artery lies quite superficially, covered only by connective tissue and skin and supported by the flat surface of the radial bone, conditions most favorable to technical investigation.

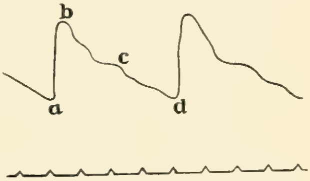

FIG. 171.—THE PULSE-CURVE OR SPHYGMOGRAM.

The sphygmogram or pulse-curve may be divided into two portions: viz., a line of ascent from a to b, and a line of descent from b to d (Fig. 171). In normal tracings the former is almost vertical and caused by the sudden expansion of the artery immediately following the ventricular contraction; the latter is in general oblique, due to the recoil of the arterial walls, occupies a longer period of time, and is marked by several elevations and depressions, both of which indicate that the restoration to equilibrium is neither immediate nor uncomplicated. One of these elevations is quite constant and known as the *dicrotic wave*, c; the depression or notch just preceding it is known as the *dicrotic notch*. Pre- and post-dicrotic waves are not infrequently present. The summit is generally sharp and pointed.

The vertical direction of the line of ascent is taken as an indication that the arterial walls expand readily, that the blood is discharged quickly, and that the ventricular action is not impeded. An oblique direction of the line of ascent is an indication that the reverse conditions obtain. The height varies inversely as the arterial pressure, other things being equal; being high with a low pressure, and low with a high pressure.

The dicrotic elevation shows that a second expansion wave is developed which interrupts temporarily the recoil of the arterial walls. The origin of this second expansion has been the subject of much investigation, and at present it may be said that the question is not fully decided. It is asserted by some investigators that it is central in origin, beginning at the base of the aorta and passing to the periphery; by others, that it is peripheral in origin, beginning near the capillary region and reflected to the heart. The former view is the one more generally accepted. According to it, the expansion is the result of the sudden closure of the aortic valves, and a backward surge of the blood column against them. The sudden arrest of the blood and its accumulations again expands the aorta.

The dicrotic notch is therefore taken as the moment at which the ventricular systole ceases and the aortic valves close. From this fact it is evident that immediately after the first expansion the pressure begins to fall, even though the ventricular systole continues, owing to the discharge of blood from the arterial into the capillary and venous systems. The height of the dicrotic wave or the depth of the dicrotic notch is favored by low arterial tension and highly elastic arteries. Both features are diminished by the reverse conditions. The apex is sometimes rounded and even flat, indicative of a great diminution in arterial elasticity. The sphygmogram not infrequently varies considerably from the normal type in different pathologic conditions of the circulatory apparatus. A consideration of these variations does not fall within the scope of this work.

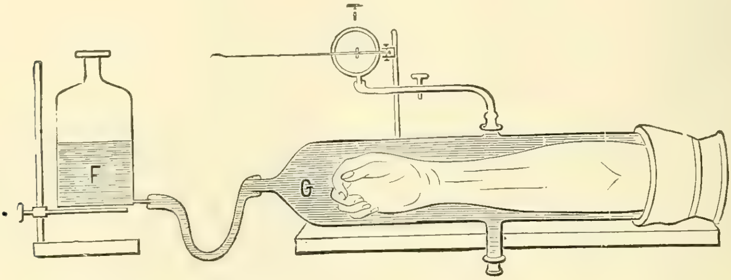

FIG. 172.—MOSSO'S PLETHYSMOGRAPH. G. Glass vessel for holding a limb. F. Flask for varying the water-pressure in G. T. Recording apparatus.—(*Landois and Stirling.*)

The Volume Pulse.—If an individual artery expands with each systole and recoils with each diastole of the heart, the same is true of all arteries, and as a result the volume of any organ or part of the body must undergo similar changes. To such alternate changes in volume the term *volume pulse* is given. The extent to which an organ will increase in volume will depend to some extent on its elasticity. The reason for the increase in volume is the resistance offered to the flow of blood into and through the capillaries; the decrease in volume to the overcoming of the resistance through the arterial recoil.

The variations in volume may be recorded by enclosing the organ in a rigid glass or metal vessel, which at one point is in communication with a recording apparatus, *e. g.*, a tambour with a lever or mercurial manometer with float and pen. The space between the organ and vessel is filled with normal saline, air, or oil. Such an apparatus is known as a *plethysmograph*. A well-known form of plethysmograph is that of Mosso (Fig. 172). Many forms of this apparatus have been devised in accordance with the character of the organ—spleen, kidney, etc.—to be investigated, though the principle underlying them is essentially the same. In addition to changes in volume due to the heart's action, most organs undergo additional changes in volume from vaso-motor and respiratory causes.

Indeed the plethysmographic is the most generally employed method to show the action of vaso-motor nerves in changing the resistance of the arterioles and hence the outflow of blood. Thus when an organ is enclosed in a plethysmograph and the arterial pressure raised by either a direct stimulation of vaso-motor nerves or a reflex stimulation of the vaso-constrictor center, there is always a decrease in the volume of the organ under observation; and on the contrary, when the vaso-dilatator nerves or centers are stimulated and the vessels dilated, there will be a fall of pressure, an increased outflow of blood and an increase in the volume of the organ. From this it is learned that the functional activity of an organ which is attended and conditioned by an increased blood-supply is always associated with an increase in volume. On plethysmographic records large undulations are frequently observed which are regarded as of respiratory origin.

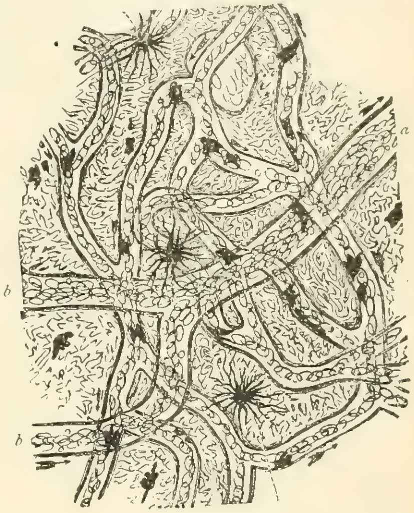

FIG. 173.—THE VESSELS OF THE FROG'S WEB. *a*. Trunk of vein, and (*b*, *b*) its tributaries passing across the capillary network. The dark spots are pigment cells.—(*Yeo's "Physiology."*)

THE CAPILLARY CIRCULATION.

In certain regions of the body of many animals it is possible, on account of the delicacy and transparency of the tissues, to observe not only the flow of blood through the smaller arteries, capillaries, and veins, but many of the phenomena connected with it, to which reference has already been made. The structures usually selected for the observation of these phenomena are the interdigital membranes (Fig. 173), the tongue, the lung, the bladder, and the mesentery of the frog. Though any one of these structures will afford an admirable view of the blood-flow, the mesentery for many reasons is the most satisfactory. For a comparison of the phenomena observed in the cold-blooded animals with those in the warm-blooded animals the omentum of the guinea-pig may be employed. If the frog is the subject of experiment, it should be slightly curarized and the brain destroyed by pithing. The animal is then placed on a small board capable of adjustment to the stage of the microscope. The abdomen is then opened along the side and a loop of intestine withdrawn and placed around a cork ring which surrounds an opening in the side of the frog board. The loop of the intestine should be so placed that it will lie between the observer and the body of the frog. The mesentery thus exposed must be kept moist with normal saline solution.

When examined with low powers of the microscope, arteries, veins, and capillaries will be found occupying the field of vision. Their general arrangement, their size and connections, can be readily determined. After a few preliminary adjustments a region will be found in which the blood is flowing in opposite directions. The vessel apparently carrying blood *away* from the observer is an artery; the vessel apparently carrying blood *toward* the observer is a vein; the smallest vessels are capillaries. The blood in the artery is of a brighter color than the blood in the vein; the blood in the capillaries is almost colorless. The arterial blood-stream not infrequently shows remittancy, an alternate acceleration and retardation, corresponding to each heart-beat; the capillary and venous streams are uniform and continuous. The relative velocities in the three sets of vessels are indicated by the movement of the red corpuscles. In the arteries they pass before the eye so rapidly that they can not be distinguished; in the capillaries they pass so slowly that both form and structure may be determined; in the veins, though again moving rapidly, they can often be distinguished.

The relative positions of the red and white corpuscles in the blood-stream are also apparent; the former occupy the central, the latter the peripheral portion, at the same time adhering to the sides of the vessel. Between the axial portion of the stream occupied by the red curpuscles and the wall of the vessel there is a clear still layer of plasma, the result of an adhesion of the plasma to the wall. It is this feature which gives rise to the friction between successive layers of the blood-stream, the resistance to the blood-flow, and the development of blood-pressure. The relative breadth of the still layer and amount of friction are greater in small than in large vessels.

The volume of blood passing into any given capillary area is determined by the degree of contraction of the arterioles. Thus on the application of warm saline solution, which relaxes the arterioles, there is a large increase in the inflow of blood; vessels previously invisible suddenly come into view as the blood with its corpuscles passes into them. On the application of cold water, which contracts the arterioles and diminishes the inflow, many of the smaller vessels entirely disappear from view. The alternate contraction and relaxation of the arterioles will therefore determine the quantity of blood flowing into and through the capillary system.

Migration of the White Corpuscles.—A phenomenon frequently observed in the capillary vessels of the mesentery or of the bladder of the frog is the passage of the white corpuscles through the walls into the surrounding lymph-spaces. To this process the term *migration* or *diapedesis* is given. After the tissues have been exposed to the air for some time or subjected to an irritant, the vessels dilate and become distended with blood. In a short time the blood-stream slows, and finally comes to rest. The condition of stasis is then established. During the development of this condition the white corpuscles accumulate in large numbers along the inner surface of the vessels and soon begin to pass through the vessel-walls. This they do by protruding a portion of their substance and inserting it into and through the vessel-wall. This once accomplished, the remainder of the cell in due time follows until it has entirely passed out into the tissue-space. The opening in the cell-wall now closes. The successive steps in this process are shown in Fig. 174. As this migration occurs mainly after the circulation has ceased or when the tissues present the phenomena of approaching inflammation, it is difficult to state in how far it is strictly a physiologic process.

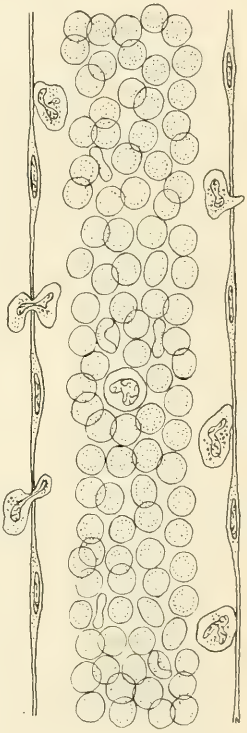

FIG. 174.—DIAGRAM TO SHOW VARIOUS STAGES IN THE DIAPEDESIS OR MIGRATION OF WHITE CORPUSCLES.

The Venous Circulation.—The blood, having passed through the capillary vessels, is gathered up by the veins and conveyed to the right side of the heart. As the veins converge and unite to form larger and larger trunks the sectional area gradually diminishes, and hence the velocity of the blood-flow increases, though it never attains the velocity, even in the venæ cavæ, that it had in the aorta, for the reason that the sectional area of the venæ cavæ is considerably larger than that of the aorta. The pressure also is very low in the larger veins because the friction still to be overcome is relatively very slight.

The capacity of the venous system is considerably greater than that of the arterial system, as there are usually two and even three veins accompanying each artery. This, taken in connection with its greater distensibility, makes of the venous system a reservoir in which blood can be stored. On this reservoir the arterial system can call for that amount of blood necessary for the maintenance of its normal volume and pressure, and into it any excess can be discharged. The relative amounts contained in the two systems are regulated by the nervous system. The movement of the blood through the veins is accomplished by the coöperation of several forces, reference to which will be made in a following paragraph.

THE PULMONIC VASCULAR APPARATUS.

The **pulmonic vascular apparatus** consists of a closed system of vessels extending from the right ventricle to the left auricle, and includes the pulmonary artery, capillaries, and pulmonary veins. In its anatomic structure and physiologic properties it closely resembles, if it is not identical with, the systemic apparatus.

The stream-bed widens from the beginning of the pulmonary artery to the middle of the capillary system; it again narrows from this point to the terminations of the pulmonary veins.

The movement of the blood from the beginning to the end of the system is due to a difference of pressure between these two points, the result of the friction between the blood and the vascular walls. From the difference in the extent of the pulmonic and systemic systems it is evident that, other things being equal, the friction is less, and therefore also the pressure is less in the former than in the latter. This view is supported by the difference in the thickness of the walls of the right and left sides of the heart. The pressure in the pulmonary artery of the dog was shown by Beutner to be about one-third that in the aorta; by Bradford and Dean to be one-fifth. The velocity of the blood-stream in each of the three divisions of the system can not well be determined. The time occupied by a particle of blood in passing from the right to the left ventricle has been estimated at one-fourth the time required to pass from the left to the right ventricle. Assuming the latter to be thirty seconds, the former would be seven and one-half seconds.

The capillary vessels are spread out in a very elaborate manner just beneath the inner surface of the pulmonary air-cells, and form, by their close relation to it, a mechanism for the excretion of carbon dioxid and the absorption of oxygen. The extent of the capillary surface is very great. It has been estimated at 200 square meters. The amount of blood flowing through this system hourly and exposed to the respiratory surface is about 800 liters. The reason for the existence of the pulmonary circulation is the renewal of the oxygen volume in the blood and the elimination of the carbon dioxid; for the accomplishment of both objects ample provision is here made. The flow of blood through the cardio-pulmonary vessels is subject to variation during both inspiration and expiration in consequence of their relation to the respiratory apparatus. The mechanism by which these variations are produced will be considered in the chapter devoted to Respiration.

FORCES CONCERNED IN THE CIRCULATION OF THE BLOOD.

1. **The Contraction of the Heart.**—The primary forces which keep the blood flowing from the beginning of the aorta to the right

side of the heart and from the beginning of the pulmonary artery to the left side are the contractions of the left and right ventricles respectively. This is evident from the fact that each ventricle at each contraction not only overcomes the pressure in the aorta and pulmonary artery, the sum of all resistances, but imparts a given velocity to the blood. Since the pressure continuously falls from the beginning to the end of each system, it follows that the blood must flow from the point of high to the point of low pressure. During the interval of the heart's activity the walls of the arteries, to which the heart's energy was largely transferred, now take up and continue the work of the heart, and by recoiling drive the blood forward and into the venous system. Though the heart's energy is probably sufficient to drive the blood into the opposite side of the heart, it is supplemented by other forces—*e. g.:*

2. **Muscle Contraction.**—As a result of the relation which the veins bear to the muscles in all parts of the body it is clear that with each contraction and relaxation of the muscles there will be exerted an intermittent pressure on the veins. With each contraction, the blood on the proximal side will at once be driven forward with increased velocity, while that on the distal side will be retarded, will accumulate and distend the veins, owing to the closure of the valves; with the relaxation of the muscle the elastic and contractile tissues in the walls of the veins will come into play and force the blood forward.
3. **Thoracic Aspiration.**—The inspiratory movement aids the flow of blood through the venæ cavæ and their tributaries. With each inspiration the pressure within the thorax but outside the lungs undergoes a diminution more or less pronounced in accordance with the extent of the movement. As a result, the blood in the large veins outside of the thorax, being now subjected to a pressure greater than that in the thorax, flows more rapidly toward the heart. With each expiration the reverse obtains.
4. **Action of the Valves.**—It is quite probable that gravity opposes to some extent the flow of blood through the veins below the level of the heart. This opposition to the upward flow is largely prevented by the valves, for each retardation is immediately checked by their closure and support given to the column of blood. The influence of gravity is shown when the relation of the arm to the heart is changed. Thus, if the arm be allowed to hang passively by the side of the body, the veins, especially on the back of the hand, will become distended with blood. If now the arm be raised, the blood will flow rapidly toward the heart, as shown by the rapid emptying of the veins.

Work Done by the Heart.—The work which the left ventricle performs at each contraction when it discharges its contained volume of blood into the aorta is:

1. To overcome the total resistance of the systemic vascular apparatus expressed in terms of aortic pressure; and—
2. To impart velocity to the blood.

The pressure in the aorta is not absolutely determined, though for many reasons it may be assumed to be about 150 mm. Hg., or its equivalent, a column of blood 1.93 meters in height. If the volume of blood which the heart discharges is assumed to be 188 grams, the work done may be calculated by multiplying the weight by the height: viz., $0.188 \times 1.93 = 0.3628$ kilogrammeter.

The velocity of the blood in the aorta has been approximately estimated at 0.5 meter per second. The work done in imparting this velocity to 188 grams is estimated by squaring the velocity and dividing by the accelerating force of gravity $(\frac{.5^2}{2 \times 9.81})$ and multiplying the quotient by 0.188. The quotient of the first two values represents the distance a body would have to fall to acquire this velocity: viz., 0.0127 meter. The work done is therefore 0.188×0.0127, or 0.0023 kilogrammeter.

The entire work of the left ventricle is the sum of these two amounts, or 0.3651 kilogrammeter. Assuming that the heart beats 72 times per minute, the work done daily would be $0.604 \times 72 \times 60 \times 24$, or 37,857.6 kilogrammeters. The right ventricle approximately performs about one-third of this amount of work in overcoming the resistance offered by the pulmonary system and in imparting velocity to its contained volume of blood. The work of the entire heart would therefore be for the twenty-four hours about 50,476 kilogrammeters.

THE NERVE MECHANISM OF THE VASCULAR APPARATUS.

The middle coat of the arteries, and especially of those in the peripheral region of the arterial system, consists of well-defined layers of non-striated muscle-fibers arranged in a circular direction or at right angles to the long axis of the vessel. In the physiologic condition these fibers are in a state of continuous contraction, more or less pronounced, and give to the arteries a certain average caliber which permits a definite volume of blood to flow through them in a given unit of time.

The cause of this tonic contraction is not definitely known. It has been attributed to the action of local nerve-ganglia, to the pressure of blood from within, to the influence of organic substances in the blood, the products of gland activity: *e. g.*, adrenalin or epinephrin.

This tonic contraction of the vascular muscle is subject to increase or decrease in accordance with the action of various agents. Increased contraction will result in a decrease of the caliber and a reduction in the outflow of blood. Decrease of the contraction or relaxation will result in an increase both of the caliber and outflow of blood. The small arteries thus determine the volume of blood passing to any given area or organ in accordance with its functional activities.

The Vaso-motor Nerves.—The activities of the vascular muscle are regulated by the central nerve system through the intermediation of nerve-fibers, termed *vaso-motor* nerves. Of these there are two kinds, one which increases or augments the contraction, the *vaso-constrictors* or *vaso-augmentors;* another which decreases or inhibits the contraction, the *vaso-dilatators* or *vaso-inhibitors.*

The vaso-motor nerves of both classes, unlike the ordinary motor nerves, do not pass directly to the muscle-fiber, but indirectly by way of the ganglia of the sympathetic nerve system. In these ganglia the vaso-motor nerves, which come from the central nerve system, terminate, breaking up into tufts, which arborize around the nerve-cells. From the cells new nerve-fibers arise which then pass without interruption to their final destination.

The nerve-fibers which emerge from the central nerve system are extremely fine in caliber and medullated; those which emerge from the sympathetic ganglia are equally fine, but non-medullated. The former are termed *pre-ganglionic,* the latter *post-ganglionic* fibers. The ganglion in which the pre-ganglionic fibers end is not necessarily found in the pre-vertebral or lateral chain; it may be found in the collateral or even in the peripheral group of ganglia.

The Vaso-constrictor Nerves.—The *vaso-constrictor nerves* take their origin from nerve-cells located in the anterior horns and lateral gray matter of the spinal cord. They emerge from the cord in company with the fibers which compose the anterior roots of the spinal nerves from the second thoracic to the second or third lumbar nerves inclusive. A short distance from the cord they leave the anterior roots as the white rami communicantes and enter the pre-vertebral or lateral sympathetic ganglia. From the results of many observations and experiments it is probable that the great majority of the vaso-constrictor nerves terminate in these ganglia; that is to say, it is here that the pre-ganglionic fibers arborize around the contained nerve-cells. From the nerve-cells new fibers arise, the post-ganglionic, which pass to the blood-vessels of the head, to the upper and lower extremities, and to the thoracic and abdominal viscera.

The vaso-constrictors for the head emerge from the spinal cord in the first four thoracic nerves, thence pass successively into and through the ganglion stellatum (the first thoracic), the annulus of Vieussens, the inferior cervical ganglion, the sympathetic cord to the superior cervical ganglion, around the cells of which they arborize. From this ganglion the new fibers follow the carotid artery and its branches to their terminations.

The vaso-constrictors for the fore-limbs emerge from the cord in the roots of the fourth to the tenth thoracic nerves inclusive. Through the white rami they pass into the sympathetic chain, after which they take an upward direction and terminate around the cells of the ganglion stellatum. From this ganglion the new fibers enter, by way of the gray rami communicantes, the trunks of the cervical nerves which unite to form the brachial plexus and by this route pass to the blood-vessels.

The vaso-constrictors for the hind-limbs emerge from the cord in the roots of the eleventh dorsal to the second or third lumbar nerves inclusive. They then pass through the white rami to the lower lumbar and upper sacral ganglia. Thence by way of the gray rami they pass into the nerve-trunks which unite to form the sacral nerves and by this route pass to the blood-vessels.

The vaso-constrictors for the viscera of the abdominal cavity pass by way of the splanchnic nerves directly into the collateral ganglia, the semilunar, the superior mesenteric, the inferior mesenteric, and the sacral. From these ganglia an elaborate network of non-medullated fibers passes to the blood-vessels of the stomach, intestines, and other viscera. The great splanchnic nerve is one of the most important vaso-constrictor trunks of the body, on account of the large vascular area it controls.

The existence, course, distribution, and functions of the vaso-constrictor nerves have been determined by a variety of methods, physiologic and anatomic. Stimulation of the nerve-trunks under appropriate conditions gives rise to a contraction, division to a dilatation of the blood-vessels. The physiologic continuity of the pre-ganglionic fibers with the nerve-cells of the sympathetic ganglia has been shown by the intra-vascular injection or the local application of nicotin. This agent, as shown by Langley, has a selective action on the arborizations of the pre-ganglionic fibers, and when given in sufficient doses suspends their conductivity; hence stimulation of the pre-ganglionic fibers is without effect, though stimulation of the post-ganglionic fibers is followed by the usual contraction.

The following will serve as illustrations of the functions of vaso-constrictor nerves. Division of the great splanchnic is followed by a marked dilatation of the blood-vessels of the intestinal tract; stimulation of the peripheral end by their contraction. Division of the cervical cord of the sympathetic is followed by dilatation of the blood-vessels of the side of the head; stimulation of the peripheral end by their contraction.

The Vaso-dilatator Nerves.—The *vaso-dilatator* nerves have their origin for the most part in nerve-cells situated in the region of the spinal cord included between the origins of the second dorsal to the second lumbar nerves inclusive, though they are not confined to this region. Some vaso-dilatator fibers have their origin in the medulla oblongata, others in the sacral region of the spinal cord.

The general course of the dilatator fibers for the intestinal tract is the same as that of the vaso-constrictors, though instead of becoming related to the nerve-cells in the pre-vertebral ganglia, they pass by way of the splanchnics to the collateral ganglia, the semilunar, the superior and inferior mesenteric, and perhaps to peripheral ganglia in or near the blood-vessels themselves.

The vaso-dilatators for the limbs are found in the common nerve-trunks associated with the usual motor and sensor fibers, though the exact route by which they pass from the spinal cord to the peripheral nerves has not in all cases been determined. Their cell stations have not been definitely located. The vaso-dilatator nerves for the blood-vessels of the submaxillary gland arise in the medulla, pass outward in the trunk of the facial nerve, and reach the gland by way of the *chorda tympani* branch. Their cell station is in the ganglion near the hilum of the gland. The vaso-dilatator nerves for the blood-vessels of the corpora cavernosa of the penis, the *nervi erigentes*, have their origin in the sacral region of the spinal cord; and emerge in the roots of the second and third sacral nerves. Their cell station is in the ganglion near the organ.

The existence, course, distribution, and functions of the vaso-dilatator fibers have been determined by the same methods employed in the investigation of the vaso-constrictors. Thus division and stimulation of the peripheral end of the chorda tympani nerve are at once followed by an active dilatation of the blood-vessels of the submaxillary gland. The inflow of blood is so great that the gland becomes bright red in color. Its tissues being unable to appropriate all the oxygen, the blood emerges in the veins almost arterial in character. Stimulation of the peripheral ends of the divided nervi erigentes is followed by similar effects in the blood-vessels of the corpora cavernosa. Slow stimulation, once per second, of the peripheral end of a divided sciatic nerve is followed by dilatation of the blood-vessels of the leg.

From these and many other facts of a similar character it is highly probable that the blood-vessels of each organ are under the control of two antagonistic classes of nerve-fibers, one augmenting the degree of their contraction, the vaso-constrictors, the other diminishing it through inhibition, the vaso-inhibitors. Through the coöperative antagonism of these two classes of nerves the caliber of the blood-vessels and thereby the volume of the blood is accurately adapted to the needs of each organ both during rest and during activity. It is also to the alternate activity of these nerves that the variations occurring from time to time in the volume of organs are to be attributed.

Physiologic Properties.—The vaso-constrictors and the vaso-dilatators differ somewhat in their physiologic properties, as shown by the results of experiment. Thus, when a mixed nerve, *i. e.*, one containing both classes of fibers—*e. g.*, the sciatic—is stimulated with frequently repeated induced currents, the constrictor effect is the more pronounced, the dilatator effect being wanting or prevented; when stimulated with slowly repeated induced currents, the dilatator effect is the more pronounced. These different effects are strikingly shown in Fig. 175, A and B.

In the experiment of which these tracings are the result the leg of a cat was enclosed in a plethysmograph and the variations in volume due to dilatation or contraction of the vessels, following stimulation of the sciatic nerve, were recorded by means of a tambour and lever on a slowly revolving cylinder. In *A* the fall of the curve indicates a diminution of volume, from contraction of blood-vessels following a rate of stimulation of the sciatic nerve of 16 per second for fifteen seconds. In *B* the rise of the curve indicates an increase in volume from dilatation of the vessels following a rate of stimulation of 1 per second for fifteen seconds (Bowditch and Warren). With different rates of stimulation somewhat different results are obtained.

After division of a mixed nerve the vaso-constrictors degenerate and lose their influence over the blood-vessel in from four to five days, the vaso-dilatators in from seven to ten days, as shown by the response to electrical stimulation.

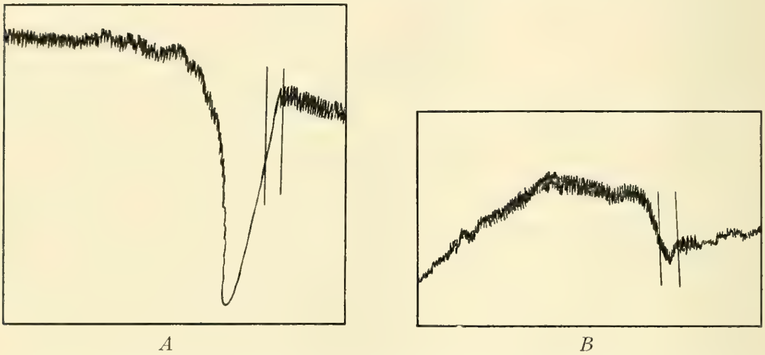

FIG. 175.—PLETHYSMOGRAMS OF THE HIND-LEG OF THE CAT FOLLOWING STIMULATION OF THE SCIATIC NERVE. In *A* the rate of stimulation was sixteen per second, in *B* one per second for fifteen seconds.

When a nerve is cooled, the vaso-constrictors lose their irritability before the vaso-dilatators.

Vaso-motor Centers.—The nerve-cells throughout the spinal cord from which the vaso-motor nerves take their origin may be regarded as nerve-centers which through their related nerve-fibers exert from time to time either a constrictor or a dilatator influence over the blood-vessels. Though both the vaso-constrictor and vaso-dilatator centers are in a state of continuous activity, the former decidedly preponderates, as shown by the maintenance of a tonic contraction of the blood-vessels. The activity of both centers may be increased or decreased, augmented or inhibited, by nerve impulses reflected to them from the periphery through afferent nerves or through nerve-fibers descending the cord from higher levels of the nerve system. Experiment has shown that when a definite region of the medulla oblongata is punctured or in anywise destroyed there is an immediate dilatation of the blood-vessels throughout the body and a fall of blood-pressure below one-half or one-third of the normal value. This region has a width of one and a half millimeters and extends longitudinally for a distance of four or five millimeters, terminating at a point four millimeters above the tip of the calamus scriptorius.

A transection of the medulla above the upper limit of this area is without effect on the blood-pressure. A similar section below it, however, is at once followed by vascular dilatation, a loss of vascular tone, and a general fall of blood-pressure. Subsequent stimulation of the peripheral end of the divided medulla, the animal being curarized and artificial respiration maintained, will give rise to a marked contraction of the blood-vessels and a rise of blood-pressure up to and far beyond the normal value.

If the experimental lesion is limited to the area mentioned in the foregoing paragraph, the vascular dilatation passes away after a time, the blood-vessels regain their normal tone, and the pressure again rises. These facts indicate that there is in the gray matter beneath the floor of the fourth ventricle, a restricted area composed of nerve-cells, which maintains through efferent nerve-fibers the tonus of the blood-vessels by virtue of its dominating influence over the vaso-motor centers in the cord, and which is therefore to be regarded as the *general vaso-motor (constrictor) center.* The vaso-motor centers throughout the cord are to be regarded as subsidiary centers. The nerve-fibers which transmit the regulative nerve impulses from the general to the subsidiary centers are to be found in the lateral columns of the spinal cord.

Since the blood-vessels maintain a more or less constant tone, it is assumed that the vaso-motor center is in a state of continuous activity. In how far, however, this activity is the result of chemic changes between the cells and the surrounding lymph and blood, or the result of constantly arriving nerve impulses reflected from the periphery or from higher regions of the nerve system, is not readily determinable. Both factors are probably involved.

A general *vaso-dilatator center* has never been located and there are many reasons for thinking that such a center has no anatomic existence. There are, however, special or local vaso-dilatator centers in the medulla oblongata and in various regions of the spinal cord and especially in the lumbar region.

Direct Stimulation of the Vaso-motor Centers.—The general vaso-motor (constrictor) center at least is markedly influenced by the quantity and quality of blood and lymph circulating around and through it. If the blood-supply to the medulla and associated structures be diminished by compression of the carotid arteries, the activity of the center is at once increased, as shown by increased vascular contraction and a rise of pressure. Restoration of the blood-supply is followed by a return of the center to its normal degree of activity. Increased blood-supply, as in cerebral hyperemia, is attended by a fall in blood-pressure indicating a decrease in the activity of the center. A diminution in the percentage of oxygen or an increase in the percentage of CO_2 in the blood will increase the activity of the center. In asphyxia especially, the center is extremely excitable, as shown by a rise of the arterial tension. The subsidiary centers in the spinal cord are influenced by corresponding conditions.

Reflex Stimulation of the Vaso-motor Centers.—The results of experiment make it certain that the degree of vascular contraction maintained by the vaso-motor centers can be increased or decreased by nerve impulses reflected to the cord and medulla from the periphery or from the brain. The effect may be general, or local and confined to the area from which the impulses arise. The following experiments may be cited as illustrations:

Stimulation of the central end of a divided posterior root of a spinal nerve gives rise to increased vascular contraction, as shown by the rise of blood-pressure. Stimulation of the central end of the divided sciatic will give rise to opposite results, according to the strength of the stimulus, weak stimuli producing dilatation, strong stimuli producing contraction of the vessels. Stimulation of the central end of the divided vagus gives rise to dilatation of the vessels of the lips, cheeks, and nasal and palatal mucous membranes. Stimulation of the tongue is followed by dilatation of the vessels of the submaxillary gland. Stimulation of certain branches of the vagus nerve is followed by a passive dilatation of blood-vessels and a marked fall of pressure. Stimulation of the peripheral terminations of the afferent nerves of the glans penis will give rise to an active dilatation of the blood-vessels of the corpora cavernosa, etc.

A satisfactory explanation of these different results is, however, wanting. By some investigators it is believed that the usual variations in the arteriole contraction are the outcome of corresponding variations in the activity of the general vaso-constrictor center the result of nerve impulses coming through afferent nerves.

The preceding statements as to the effects on the degree of vascular contraction, and hence on the blood-pressure which follow stimulation of different afferent nerves, has led to the assumption that there are in most afferent nerves two classes of nerve-fibers, though perhaps in varying proportions, one of which when in activity augments, the other of which when in activity inhibits the activity of the vaso-constrictor center. The former class is generally termed *pressor*, the latter *depressor fibers*.

It is possible, therefore, that under physiologic conditions, physiologic stimuli act on the peripheral terminations of either the one or the other; according as they do will the center be augmented or inhibited in its activity, and attended by either an increase or a decrease in the degree of the previous vascular contraction.

Again it may be assumed, from the results of experimentation on afferent nerves, that the physiologic stimuli may act simultaneously on the peripheral terminations of both classes of fibers and that the vaso-constrictor center is acted on by the two antagonistic influences. In this assumption the resultant effect on the blood-vessels, viz., increased or decreased contraction, will be the resultant of their action on the vaso-constrictor center. If the stimuli act preponderantly on the depressor fibers the center will be depressed and the vessels will dilate; if they act preponderantly on the pressor fibers the center will be stimulated and the vessels will contract.

Inasmuch as the vascular dilatation is often greater than the dilatation which follows division of the vaso-motor fibers themselves, it has been assumed by some that the general vascular tonus, as well as its variations from time to time, is the resultant of the simultaneous activity and variations in activity of both vaso-constrictor and vaso-dilatator centers; that in the afferent nerves there are two sets of fibers, one of which when stimulated augments the activity of the vaso-constrictor center and inhibits the activity of the vaso-dilatator center; the other of which auguments the activity of the vaso-dilatator center and inhibits the activity of the vaso-constrictor center. The result, either contraction or dilatation, which follows stimulation of their peripheral terminations will depend on the character of the physiologic stimulus.

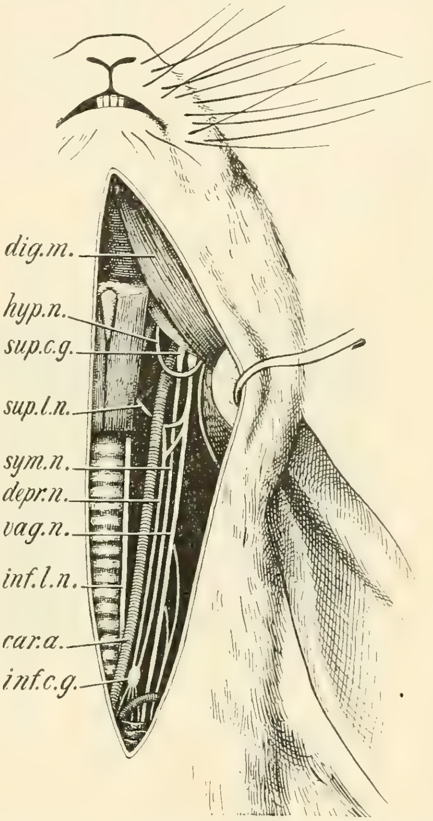

FIG. 176.—DIAGRAM SHOWING THE ORIGIN AND RELATION OF THE DEPRESSOR NERVE IN THE RABBIT. Depr. n., depressor nerve; vag. n., vagus nerve; sup. l. n., superior laryngeal nerve; inf. c. g., inferior cervical ganglion; sym. n., sympathetic nerve; car. a., carotid artery; dig. m., digastric muscle; hyp. n., hypoglossal nerve; sup. c. g., superior cervical ganglion; inf. l. n., inferior laryngeal nerve.

In those particular instances in which stimulation of the peripheral terminations of afferent nerves, *e. g.*, the nervi erigentes and chorda tympani, is followed by active dilatation of the blood-vessels, it has been assumed that there are afferent nerve-fibers which directly stimulate or augment the activity of a special vaso-dilatator center and for this reason should be termed "reflex vaso-dilatator nerves" (Hunt).

The Influence of Emotional States.—The vaso-motor centers are capable of being influenced in their activities by emotional states, doubtless as a result of the arrival of nerve impulses from the cortex of the cerebrum. Thus it is well known that fear causes a contraction of the blood-vessels of the head and face and that shame causes a dilatation of the same vessels. With the cessation or the disappearance of the emotional state, the blood-vessels return to their former degree of contraction.

The Depressor Nerve.—A striking illustration of the depressor or inhibitor action of afferent nerves upon the vaso-constrictor center is furnished by the result of stimulation of a branch of the vagus, the so-called "depressor nerve." In the rabbit, Fig. 176, there is a small nerve formed by the union of a branch from the trunk of the vagus with a branch from the superior laryngeal. The peripheral distribution of this nerve is over the wall of the ventricle and perhaps to some extent to the structures of the arota near its origin. A similar anatomic arrangement is met with in the horse, pig, and hedge hog. In some other animals, as the dog, it is bound up in the vago-sympathetic. In man it is also present, though shortly after its origin it enters the trunk of the vagus. Division of this nerve is without effect either on the heart or the vessels. Stimulation of the peripheral end has neither an accelerator nor an inhibitor action on the heart. Stimulation of the central end is followed by a fall in blood-pressure, frequently to a level below one-half the normal value; at the same time there is a diminution, brought about reflexly, in the rate of the heart-beat (Fig. 177). The fall in pressure, however, is not due to this cause, for it occurs equally well after division of all the cardiac nerves. For this

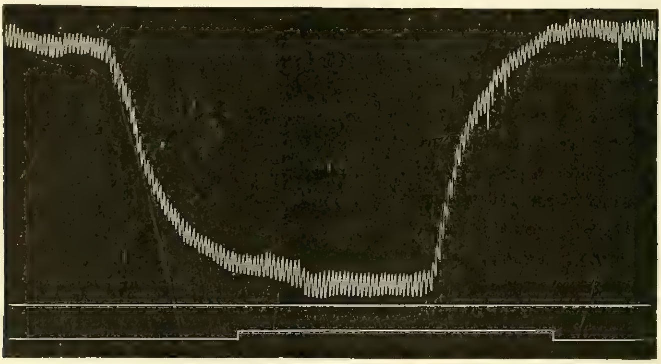

FIG. 177.—FALL OF BLOOD-PRESSURE FROM EXCITATION OF THE DEPRESSOR NERVE. The cylinder was stopped in the middle of the curve and the excitation maintained for seventeen minutes. The line of zero pressure (0,0) should be 30 mm. lower than here shown.—(*Bayliss.*)

reason the nerve was termed the depressor nerve of the vaso-motor center.

On exposure of the abdominal cavity, it is observed during stimulation of the depressor that there is a notable dilatation of the intestinal vessels. From this fact it was assumed that the action of the depressor nerve was to lower the general pressure through reflex dilatation of these vessels. It has been shown by Porter and Beyer that if the splanchnics are divided and the peripheral end stimulated so as to maintain the tonus of the intestinal vessels, and hence the general pressure, stimulation of the depressor nerve will nevertheless be followed by a fall of the blood-pressure almost as great as when the splanchnics are intact. From this it is evident that the depressor nerve is related to centers which influence the vascular apparatus in its entirety. It has been supposed that through it the heart can protect itself from injurious results of an excessive rise of arterial pressure.

Thus, when the intra-cardiac pressure or the intra-aortic pressure rises beyond a normal amount from increased resistance, the peripheral terminations of this nerve are stimulated with the result that the vaso-motor center is inhibited and the arterioles relaxed. Through this means the pressure falls and the work of the heart is lessened.

CHAPTER XV.

RESPIRATION.

Respiration is a process by which oxygen is introduced into, and carbon dioxid removed from, the body. The assimilation of the former and the evolution of the latter take place in the tissues as a part of the general process of nutrition. Without a constant supply of oxygen and an equally constant removal of the carbon dioxid, those chemic changes which underlie and condition all life phenomena could not be maintained.

The general process of respiration may be considered under the following headings, viz.:

1. The anatomy and general arrangement of the respiratory apparatus.
2. The mechanic movements of the thorax by which an interchange of atmospheric and intra-pulmonary air is accomplished.
3. The chemistry of respiration, the changes in composition undergone by the air, blood, and tissues.
4. The nerve mechanism by which the respiratory movements are maintained.

THE RESPIRATORY APPARATUS.

The respiratory apparatus consists essentially of:

1. The lungs and the air-passages leading into them: viz., the nasal chambers, mouth, pharynx, larynx, and trachea.
2. The thorax and its associated structures.

The **nasal chambers** are the natural entrances for the inspired air. Their complicated structure slightly retards the movement of the air, in consequence of which its temperature and moisture are adjusted to the physiologic conditions of the lower respiratory passages. The mouth, though frequently serving as an entrance for air, is not primarily a respiratory passage. Both the nasal chambers and the mouth communicate posteriorly with the pharynx, in which the respiratory and the deglutitory passages cross each other, the former leading directly into the larynx.

The **larynx** is a complicated mechanism serving the widely different though related functions of respiration and phonation. It consists of a framework of cartilages, articulating one with another, united by ligaments and moved by muscles; it is covered externally with fibrous tissue and lined with mucous membrane. The superior opening of the larynx, the glottis, is triangular in shape, the base being directed upward and forward, the apex downward and backward. The inclination of the glottic opening is almost vertical.

The cavity of the larynx is partially subdivided by the interposition of the vocal bands into a superior and an inferior portion. The opening, bounded by the vocal bands, is also triangular in shape, though in this case the base is directed backward, the apex forward. (See chapter on Voice and Speech.)

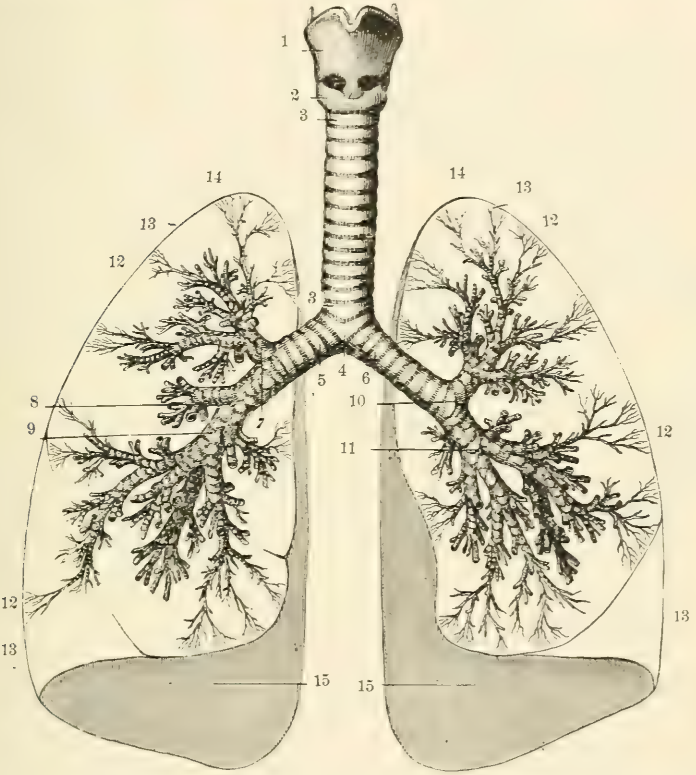

FIG. 178.—TRACHEA AND BRONCHIAL TUBES. 1, 2. Larynx. 3, 3. Trachea. 4. Bifurcation of trachea. 5. Right bronchus. 6. Left bronchus. 7. Bronchial division to upper lobe of right lung. 8. Division to middle lobe. 9. Division to lower lobe. 10. Division to upper lobe of left lung. 11. Division to lower lobe. 12, 12, 12, 12. Ultimate ramifications of bronchi. 13, 13, 13, 13. Lungs, represented in contour 14, 14. Summit of lungs. 15, 15. Base of lungs.—(*Sappey.*)

The introduction of the vocal bands narrows at this level the air-passage and to some extent interferes with the free entrance of air. According to the investigations of Semon, the area of the air-passage above and below the phonatory apparatus is about 200 sq. mm.; while the area bounded by the vocal apparatus is but 155 sq. mm. during quiet respiration.

The **trachea** is a tube, some 12 centimeters in length, from one-half to three-fourths of a centimeter in breadth, extending from the lower border of the larynx to a point opposite the fifth dorsal vertebra. It consists of an external fibrous and an internal mucous membrane, between which is a series of superposed C-shaped arches or rings of elastic cartilage, some 18 or 20 in number. Between the fibrous and mucous coats posteriorly, and occupying the space between and attached to the free ends of the cartilages, there is a layer of transversely arranged non-striated muscle-fibers, known as the *tracheal* muscle. The alternate contraction and relaxation of this muscle would by varying the distance between the ends of the cartilages, either diminish or increase the caliber of the trachea. The surface of the mucous membrane is covered by a layer of stratified columnar ciliated epithelium (Fig. 179). In the submucous tissue there are a number of glands the ducts of which open on the free surface.

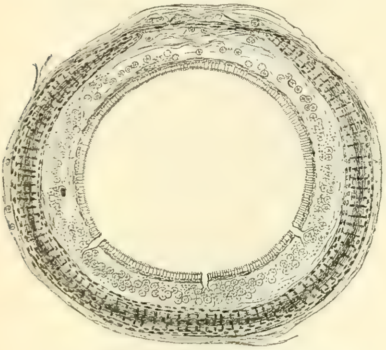

FIG. 179.—TRANSVERSE SECTION OF THE TRACHEA OF A KITTEN.—(*Stirling.*)

Opposite the fifth dorsal vertebra the trachea divides into a right and a left bronchus. Each bronchus again subdivides into two or three branches, which penetrate the corresponding lung.

The **lungs,** in the physiologic condition, occupy the greater part of the cavity of the thorax. They are separated from each other by the contents of the mediastinal space: viz., the heart, the large blood-vessels, the esophagus, etc. Each lung is somewhat pyramidal in shape with the apex directed upward. The outer surface is convex and corresponds to the general conformation of the thorax. The inner surface is concave and accommodates the contents of the mediastinal space. At about the middle of the inner surface there enter the lung, the bronchi, and blood-vessels. The under surface of the lung is concave and rests on the diaphragm. The posterior border is convex; the anterior border is thin.

A histologic analysis of the lung shows it to consist of the branches of the bronchi, their subdivisions and ultimate terminations, blood-vessels, lymphatics and nerves, imbedded in a stroma of fibrous and elastic tissue. The anatomic relations which these structures bear one to another is as follows:—

Within the substance of the lung the bronchi divide and subdivide, giving origin to a large number of smaller branches, *the bronchial tubes*, which penetrate the lung in all directions. With this repeated subdivision the tubes become narrower, their walls thinner, their structure simpler. In passing from the larger to the smaller tubes the cartilaginous arches become shorter and thinner, and finally are represented by small angular and irregularly disposed plates. In the smallest tubes the cartilage entirely disappears. With the diminution of the caliber of the tube and a decrease in the thickness of its walls, there appears a layer of non-striated muscle-fibers, the so-called *bronchial muscle*, between the mucous and submucous tissues, which completely surrounds the tube and becomes especially well developed in those tubes devoid of cartilage. The fibrous and mucous coats at the same time diminish in thickness.

The bronchial muscles are presumably in a state of tonic contraction and impart to the bronchial tubes a certain average caliber best adapted for respiratory purposes. Experimental investigations indicate that they are innervated by efferent fibers of the vagus nerve, inasmuch as stimulation of this nerve is usually followed by a contraction of the muscles and a narrowing of the lumen of the bronchial system. These muscles may also be thrown into increased activity by the inhalation of irritating gases and into a tetanus by pathologic causes as seen in the various forms of asthma.

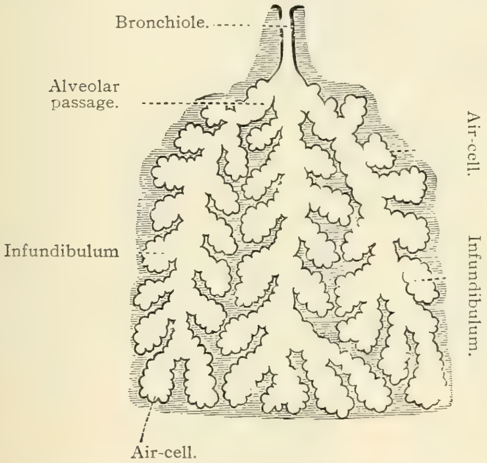

FIG. 180.—SCHEME OF A BRONCHIOLE TERMINATING IN ALVEOLAR PASSAGES, THOSE LEADING INTO INFUNDIBULA BESET WITH AIR-CELLS.—(*Landois and Stirling.*)

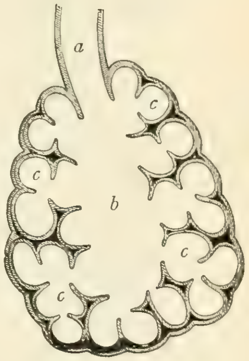

FIG. 181.—SINGLE LOBULE OF HUMAN LUNG. *a.* Alveolar passage. *b.* Cavity of lobule or infundibulum. *c.* Pulmonary sacs.—(*Dalton.*)

When the bronchial tube has been reduced to the diameter of about one millimeter, it is known as a *bronchiole* or a *terminal bronchus*. From the sides of the terminal bronchus and from its final termination there is given off a series of short branches which soon expand to form lobules or alveoli (Fig. 180). The cavity of the alveolus is termed the infundibulum. From the inner surface of the alveolus and of the passageway leading into it, there project thin partitions which subdivide the outer portion of the general cavity or infundibulum into small spaces, the so-called air-sacs or air-cells (Fig. 181). The wall of the alveolus is extremely thin and consists of fibro-elastic tissue, supporting a very elaborate capillary network of blood-vessels. The bronchial system as far as the aveolar passages is lined by ciliated epithelium. The air-sacs are lined by flat epithelial plates of irregular shape, termed the *respiratory epithelium* (Fig. 182). The alveoli are united one to another by fibro-elastic tissue.

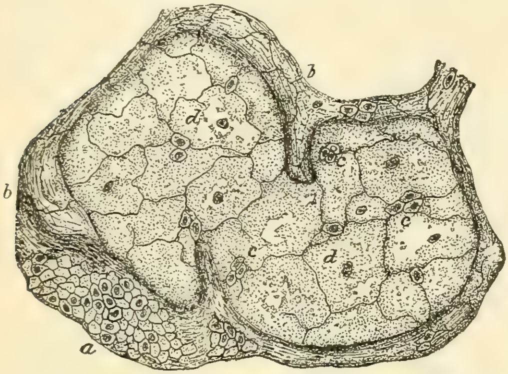

Fig. 182.—Section of Silvered Lung of Kitten, including Portions of Infundibulum and Air-sac. *a*. Small polyhedral epithelial cells covering the wall of the infundibulum. *b*. Fibro-elastic framework. *c*. Large flattened epithelial plates lining air-sac, among which lie small groups of small cells (*d*).—(*Piersol.*)

The bronchial arteries which supply nutritive material to the pulmonary structures arise from the aorta as a rule, though sometimes from an intercostal artery. Each lung receives two arteries which accompany the bronchi as far as the distal ends of the alveolar passages. From the capillary network formed out of the terminals of these arteries, two systems of veins arise, one of which returns the blood from the larger tubes and empties it into the azygos vein; the other of which returns the blood from the smaller tubes and the alveolar passages, and empties it into the pulmonary veins. The blood in the pulmonary veins, though largely arterialized, nevertheless contains some venous blood derived from the veins arising from the capillary network of the bronchial arterioles.

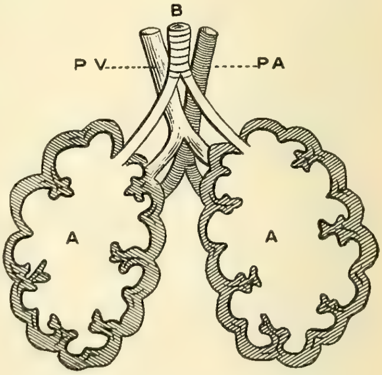

Fig. 183.—The Relation of the Pulmonary Artery, PA, and the Pulmonary Vein, PV, to the Lobules, AA. B. The Bronchiole.

The nerves distributed to the muscle-fibers of the bronchial arteries, and of the bronchial tubes and to the mucous membrane, are derived from the vagus and the sympathetic and enter the substance of the lung at and around its root.

In consequence of the presence of the elastic tissue, the lungs are distensible and elastic. After removal from the body the elastic tissue at once recoils, forcing out a portion of the contained air. The condition of the lung is now one of collapse. Under pressure, however, the lung can be readily distended or inflated. These properties endure for a long period after death, if not indefinitely, if the lungs are properly preserved. The capacity of the lungs can be made to vary within rather wide limits in virtue of the presence of the elastic tissue.

The Pulmonary Blood-vessels.—The pulmonary artery which conducts the venous blood from the heart to the lungs divides beneath the arch of the aorta into a right and a left branch. Each branch with its subdivisions enters the lung at the hilum in company with the larger divisions of the bronchi. Within the lung the arteries divide and subdivide in a manner corresponding to that of the bronchial tubes, which they follow to their ultimate terminations. As the pulmonary lobules are approached, a small arterial branch plunges into the wall of the lubule (Fig. 183), in which it forms an elaborate capillary network which surrounds and embraces the air-sacs on all sides. As this network is to subserve the respiratory exchange of gases it lies nearer the inner than the outer surface of the lobule and in close rela-

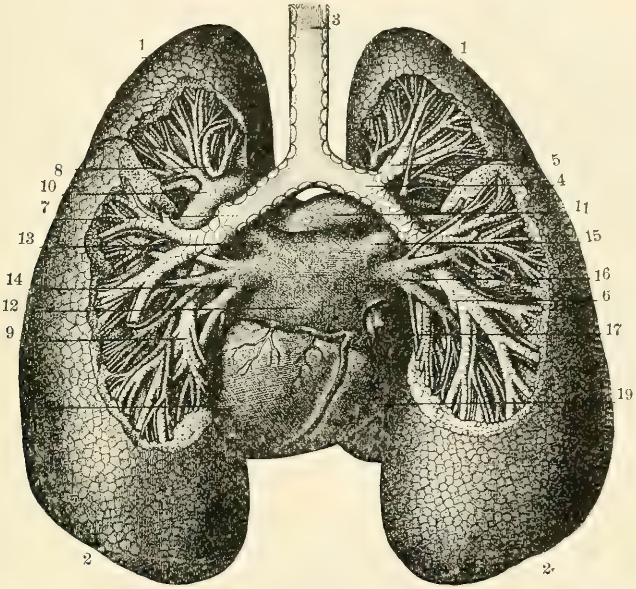

FIG 184.—BRONCHI AND LUNGS, POSTERIOR VIEW. 1, 1. Summit of lungs. 2, 2. Base of lungs. 3. Trachea. 4. Right bronchus. 5. Division to upper lobe of lung. 6. Division to lower lobe. 7. Left bronchus. 8. Division to upper lobe. 9. Division to lower lobe. 10. Left branch of pulmonary artery. 11. Right branch. 12. Left auricle of heart. 13. Left superior pulmonary vein. 14. Left inferior pulmonary vein. 15. Right superior pulmonary vein. 16. Right inferior pulmonary vein. 17. Inferior vena cava. 18. Left ventricle of heart. 19. Right ventricle.—(*Sappey.*)

tion to the respiratory epithelium. The air and blood are thus brought into intimate relationship, being separated only by the respiratory epithelium and the wall of the capillary vessel. The blood emerging from the capillary vessels is conducted by a corresponding converging system of vessels, the pulmonary veins, out of the lungs and into the left auricle of the heart. The main function of the pulmonary apparatus and the pulmonary division of the circulatory apparatus is to afford a ready means for the exhalation of the carbon dioxid and the absorption of oxygen. In consequence of this exchange of gases the blood changes in color from dark bluish-red to scarlet red. The relations of the heart and its vessels to the lungs and bronchial tubes are shown in Fig. 184.

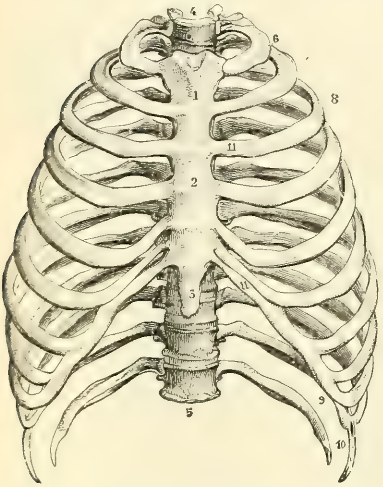

Fig. 185.—Thorax, Anterior View. 1. Manubrium sterni. 2. Gladiolus. 3. Ensiform cartilage of xiphoid appendix. 4. Circumference of apex of thorax. 5. Circumference of base. 6. First rib. 7. Second rib. 8, 8. Third, fourth, fifth, sixth, and seventh ribs. 9. Eighth, ninth, and tenth ribs. 10. Eleventh and twelfth ribs. 11, 11. Costal cartilages.

The Thorax.—The thorax, in which the respiratory organs and their associated structures are lodged, is conic in shape, though somewhat compressed from before backward. Its apex is directed upward, its base downward. The walls of the thorax are composed, first, of a bony framework or skeleton and, second, of muscles and fascia. The bony framework is formed posteriorly by the thoracic vertebræ and the posterior extremities of the ribs, laterally by the ribs, and anteriorly by the costal cartilages and the sternum. The superior opening, through which pass the trachea, esophagus, and blood-vessels, is oval in outline and measures from side to side about 12.5 cm., and from before backward about 6.25 cm. The inferior opening is of large size, but irregular in its boundaries from the upward inclination of the ribs and the downward projection of the sternum.

The **ribs** which form a large part of the thoracic walls constitute a series of bony arches attached posteriorly to the vertebræ and anteriorly to the sternum through the intermediation of their cartilages. The last two form an exception. The ribs are somewhat twisted upon themselves and pursue an oblique direction from above downward and forward. As a result the anterior extremity lies at a lower level than the posterior. The costal cartilages are directed upward and forward, with the exception of the upper three, which are almost horizontal. The general arrangement and appearance of the thorax are shown in Fig. 185.

The costo-vertebral and costo-chondral and the chondro-sternal articulations are diarthrodial in character and endow the thoracic walls with a considerable degree of mobility. The costo-vertebral joints are two in number, the first being formed by the beveled head of the rib and the bodies of two adjoining vertebræ; the second, by the tubercle of the rib and the transverse process. The costo-chondral and the chondro-sternal articulations, as their names imply, are formed by the ribs, cartilages, and sternum.

The **muscles** which complete the formation of the thoracic walls are as follows: the diaphragm, the intercostales externi and interni, the levatores costarum, the triangularis sterni, and the infra-costales.

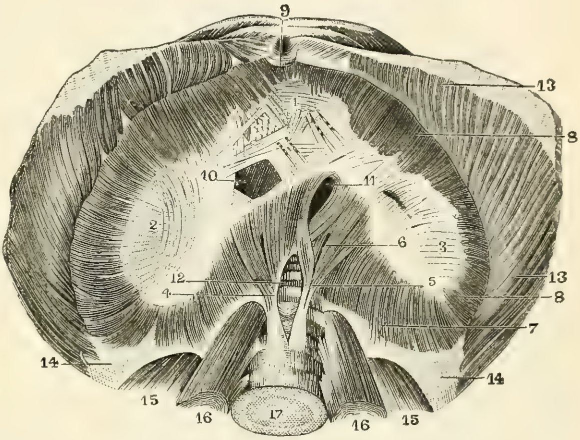

Fig. 186.—Diaphragm, Inferior Aspect. 1. Anterior and middle leaflet of central tendon. 2. Right leaflet. 3. Left leaflet. 4. Right crus. 5. Left crus. 6, 6. Intervals for phrenic nerves. 7. Muscular fibers, from which the ligamenta arcuata originate. 8. Muscular fibers that arise from the inner surface of the six lower ribs. 9. Fibers that arise from ensiform cartilage. 10. Opening for inferior vena cava. 11. Opening for esophagus. 12. Aortic opening. 13, 13. Upper portion of transversalis abdominis, turned upward and outward. 14. Anterior leaflet of transversalis aponeurosis. 15, 15. Quadratus lumborum. 16, 16. Psoas magnus. 17. Third lumbar vertebra.

The **diaphragm** is the musculo-membranous sheet which closes the inferior opening of the thorax and completely separates its cavity from that of the abdomen. It consists of two muscles which arise from the bodies of the first three or four lumbar vertebræ and neighboring fascia, from the border of the six lower ribs, and from the ensiform cartilage (Fig. 186). From this extensive origin the muscle-fibers pass centrally to be inserted into a common tendon. As the direction of the fibers is from below upward and inward, the diaphragm is somewhat dome-shaped. Its inferior border is for a short distance in contact with the sides of the thorax.

The *intercostales externi*, eleven in number on each side, occupy the spaces between the ribs to which they are attached from the tubercle to the anterior extremity (Figs. 187 and 188). Their fibers, which are arranged in parallel bundles, are directed from above downward and from behind forward. The point of attachment, therefore, of any given bundle of fibers to the rib above, lies nearer the vertebral column, nearer the fulcrum, than the point of attachment below.

The *intercostales interni*, eleven in number, occupy the spaces between, and are attached to, the ribs from the tubercle to the anterior extremity of the cartilages. Their fibers, which are also arranged in parallel bundles, are directed from above downward and backward (Figs. 188 and 189).

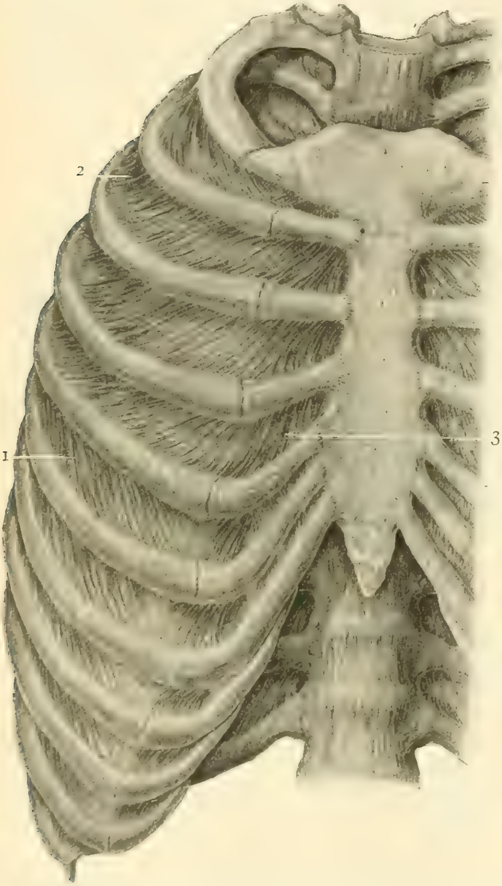

FIG. 187.—SHOWING THE SITUATION, THE POINTS OF ATTACHMENT, AND DIRECTION OF THE INTERCOSTAL MUSCLES. 1. The intercostales externi. 2. The intercostales interni. 3. The intercartilaginei.—(*Deaver.*)

The *levatores costarum* are twelve in number on either side. They arise from the tips of the transverse processes of the last cervical and the thoracic vertebræ with the exception of the last. From the point of origin the fibers pass downward and outward in a diverging manner to be inserted into the ribs between the tubercle and the angle. Their action, as their name implies, is to elevate the posterior portion of the ribs.

The *triangularis sterni* arises from the side of the posterior surface of the lower third of the sternum and is inserted by fleshy slips into the cartilages of the ribs from the second to the sixth.

From the fact that the inferior opening of the thorax as well as the intercostal spaces are completely closed by the foregoing muscles, and from the further fact that the superior is closed by fascia except at those points through which pass the trachea, blood-vessels and esophagus, the cavity of the thorax is absolutely air-tight.

The Pleuræ.—Each lung is surrounded by a closed invaginated serous sac, the pleura, of which the inner portion is reflected over and is closely adherent to the surface of the entire lung as far as its root; the outer portion is reflected over the inner wall of the thorax, the superior surface of the diaphragm, and the viscera of the mediastinum. Under normal conditions these two layers of the pleura, the visceral and parietal, are in contact, or at most separated only by a thin capillary layer of lymph. The presence of this fluid prevents appreciable friction as the two surfaces play against each other in consequence of the movements of the lungs.

THE MECHANIC MOVEMENTS OF THE THORAX.

The blood receives oxygen from, and yields carbon dioxid to, the alveoli of the lungs, as it flows through the pulmonary capillaries. That this exchange of gases may continue, it is of primary importance that the air within the alveoli be removed as rapidly as it is vitiated. This is accomplished by an alternate increase and decrease in the capacity of the thorax, accompanied by corresponding changes in the capacity of the lungs. During the former there is an inflow of atmospheric air (inspiration), during the latter an outflow of intra-pulmonary air (expiration). The continuous recurrence of these two movements brings about that degree of pulmonary ventilation necessary to the normal exchange of gases between the blood and the air. The two movements together constitute a respiratory act or cycle.

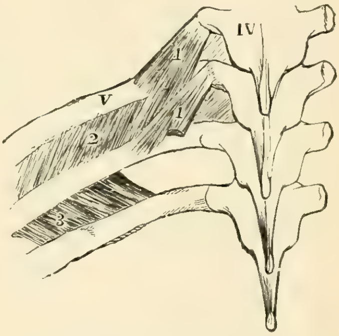

Fig. 188.—View from behind of Four Dorsal Vertebræ and Three Attached Ribs, showing the Attachment of the Elevator Muscles of the Ribs and the Intercostals. 1. Long and short elevators. 2. External intercostal. 3 Internal intercostal.—(*Allen Thomson*)

In the course of the respiratory cycles the thorax presents alternately a short period of rest—viz., between the end of an expiration and the beginning of an inspiration—and a relatively long period of activity, including both inspiration and expiration. The former may be regarded as the static, the latter as the dynamic condition of the thorax. In the static condition, the thorax and its contained and associated organs sustain a definite relation one to another; in the dynamic conditions these relations undergo a change the extent of which is proportional to the extent of the movements.*

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* It is a matter of dispute as to whether or not there is an absolute cessation of movement of the thoracic walls at the end of expiration. A graphic record of the movement shows that if there is no absolute cessation, the movement is so slight that, for the purposes here intended, a pause may be admitted. With this admission it is, however, recognized that the forces, both elastic and muscular, which are always acting on the thoracic walls, though in opposite directions, have not ceased to act, but have become so nearly equal that for a brief period they are practically in a condition of equilibrium, during which the thoracic walls are stationary.

THE STATIC CONDITION.

Relation of the Thoracic Organs.—Intra-pulmonary Pressure: Intra-thoracic Pressure.—In the *static* condition of the thorax the lungs, by virtue of their distensibility, completely fill all parts of the thorax not occupied by the heart and great blood-vessels (Fig. 189). This condition is maintained by the pressure of the air within the lungs, the *intra-pulmonary pressure*, which with the respiratory passages open, is that of the atmosphere, 760 mm. Hg. This relation persists so long as the thorax remains air-tight. If the skin and muscles covering an intercostal space be removed the lung can be seen in close contact with the parietal layer of the pleura gliding by with each inspiration and expiration. If, however, an opening be now made in the pleura sufficient to admit air, the lung immediately collapses and a pleural cavity is established. The pressure of air within and without the lung counterbalancing, at the moment the air is admitted, the elastic tissue at once recoils and forces a large part of the air out of the lung. This is a proof that in the normal condition, the lungs, distended by atmospheric pressure from within, are in a state of elastic tension and ever endeavoring to pull the visceral layer of the pleura away from the parietal layer. That they do not succeed in doing so is due to the fact that the atmospheric pressure from without is prevented from acting on the lung by the firm unyielding walls of the thorax.

Intra-thoracic Pressure.—As a result of the elastic tension of the lungs a fractional part of the intra-pulmonary pressure, 760 mm. Hg., is counterbalanced or opposed, so that the heart and great vessels and other intra-thoracic viscera are subjected to a pressure somewhat less than that of the atmosphere; the amount of this pressure will be that of the atmosphere *less* that exerted by the elastic tissue of the lung in the opposite direction, expressed in terms of millimeters of mercury. In the thorax but outside the lungs, there then prevails a pressure, negative to the pressure inside the lungs and which is known as the *intra-thoracic pressure*.

The amount of this intra-thoracic pressure can be approximately determined in several ways. Thus, if shortly after death a mercurial manometer be inserted air-tight into the trachea of a human being and the thorax opened, the lungs will recoil and compress their contained air. The mercurial manometer will at once show an excess of pressure in the trachea of about 6 mm. This was taken by Donders as a measure of the force with which the lungs endeavor to recoil. The intra-thoracic pressure would be, therefore, atmospheric pressure, 760 mm., less 6 mm., or 754 mm. Hg. Another method is to insert a rubber catheter through a small opening in an intercostal space into the thoracic cavity. The air which enters through the open extremities of the catheter and leads to a collapse of the lungs may be subsequently aspirated, when the lung returns to its normal position. The catheter is then placed in connection with a water manometer. On establishing a communication between them, by the turning of a stopcock, the water will rise in the proximal and fall in the distal limb of the manometer, indicating a pressure in the thorax *negative* to that in the lung. The difference in the level of the water in the two limbs of the manometer, expressed in millimeters of mercury, would also represent the force with which the elastic tissue strives to recoil, and the extent to which it opposes the atmospheric pressure. This subtracted from the atmospheric pressure would give the intra-thoracic pressure. In the living dog this latter is less than the former, to the extent of from 3.5 to 5.5 mm. For the same reason the superior surface of the diaphragm also experiences a pressure less than that of the atmosphere. Owing to the soft and yielding character of the abdominal walls the atmospheric pressure is transmitted through the abdominal organs to the inferior surface of the diaphragm. The pressure being greater from below than above, the diaphragm is forced upward until it assumes the dome-like appearance it usually presents. (These relations are shown in Fig. 189.)

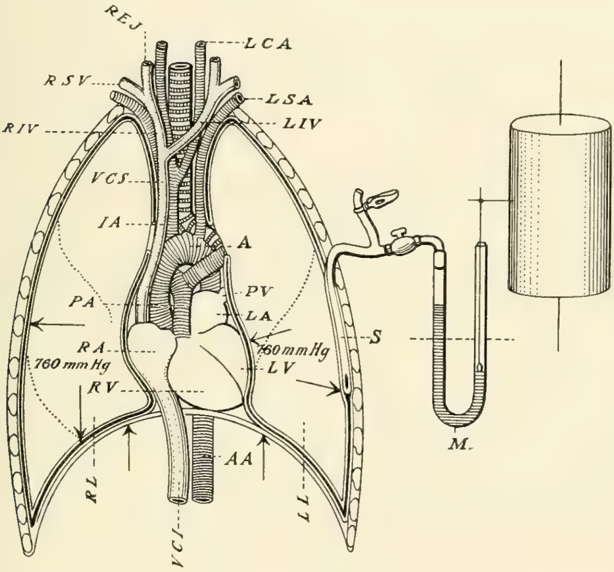


FIG. 189.—SECTION OF THORAX WITH THE LUNGS, HEART, AND PRINCIPAL VESSELS. *S.* Catheter introduced into the pleural space and connected with a manometer.—(*After Morat and Doyen.*)

The cause of the negativity of the intra-thoracic pressure is connected with the change in the relation of the lungs to the thorax attending the first inspiration. Previous to birth the walls of the alveoli and bronchioles are collapsed and in apposition. The larger bronchial tubes in all probability contain fluid. The lungs therefore are devoid of air (atelectatic), and, having a specific gravity greater than water, readily sink when placed in this fluid. The capacity of the thorax does not exceed the volume of the lungs. With the first inspiration, however, the thoracic walls take a new position. The air at once rushes into the lungs and distends them. But as the capacity of the thorax even at the end of the expiration is now greater than the volume which the lungs could assume without considerable distention, there at once arises the elastic recoil in the opposite direction, the condition which gives rise to the negativity of the pressure in the thoracic cavity. It is also probable that as the child develops, the thorax grows more rapidly than the lungs, giving rise to a condition which would increase and accentuate the elastic tension and thus increase the negativity of the intra-thoracic pressure.

THE DYNAMIC CONDITION.

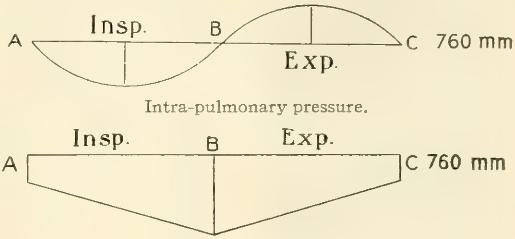
In the *dynamic* condition as previously stated these relations and pressures change. Thus the diaphragm descends, the ribs ascend, the sternum advances and the lungs expand. The *intra-pulmonary pressure* varies during both inspiration and expiration. With the enlargement of the thorax through muscle activity, there goes a corresponding increase in the size and capacity of the lungs, in consequence of the expansion and pressure of the air in the pulmonary alveoli. With the expansion of the air its pressure falls; but though it is now *less* than atmospheric, it is yet much greater than the opposing force of the lung tissue. As a result of the fall of intra-pulmonary pressure there is a rapid inflow of air, which continues until atmospheric pressure is restored; that is, at the end of the inspiration. With the diminution of the thorax, through the recoil of the elastic tissue of the thoracic and abdominal walls, there goes a corresponding decrease of lung capacity, in consequence of the recoil of the elastic tissue of the lungs. As a result, the air in the lungs becomes compressed, its pressure rises above that of the atmosphere, and a rapid outflow of air takes place, which continues until atmospheric pressure is again restored; that is, at the end of the expiration.

The cause for the fall of intra-pulmonary pressure during inspiration and the rise during expiration is to be found in the resistance offered by the air-passages to the movement of the air, throughout their entire extent, and especially at the level of the vocal bands. The greater the resistance, from whatever cause, physiologic or pathologic, the greater the variations of the pressure.

In quiet inspiration the fall of pressure, as indicated by a manometer inserted into one nostril, seldom amounts to more than 1.5 mm. of Hg., the rise in expiration, 2.5 to 3 mm. of Hg. In forcible inspiratory and expiratory efforts these limits may be largely exceeded.

Thus it was found by Donders that with one nostril closed and a mercurial manometer inserted into the other the pressure by voluntary efforts could be made to fall 57 mm. during inspiration and to rise 87 mm. during expiration. The changes in intra-pulmonary pressure are graphically represented in the upper half of Fig. 190.

The *intra-thoracic pressure* also varies during both inspiration and expiration. As the intra-pulmonary pressure falls, the recoil of the elastic tissue increases, with the result of diminishing the intra-thoracic pressure, though not in a steadily progressive manner. The fall of intra-thoracic pressure at the end of a quiet inspiration amounts to about 9 mm. Hg. In forcible inspiratory efforts this fall in intra-thoracic pressure may amount to 30 or 40 mm. of Hg. As the intra-pulmonary pressure rises above the atmospheric pressure during expiration, the recoil of the elastic tissue is again opposed, with the result of increasing the intra-thoracic pressure, though not in a steadily progressive manner. The changes in intra-thoracic pressure are graphically represented in the lower half of Fig. 190.



Intra-pulmonary pressure.

Intra-thoracic pressure.

FIG. 190.—REPRESENTING THE CHANGES, 1, IN THE INTRA-PULMONARY, AND 2, IN THE INTRA-THORACIC PRESSURES DURING INSPIRATION AND EXPIRATION.

Respiratory Movements.—As previously stated, the ventilation of the lungs is accomplished by an alternate increase and decrease in the capacity of the thorax, accompanied by corresponding changes in the lungs, the two movements being known as *inspiration* and *expiration* respectively. During the increase in the thoracic capacity, the air passively flows into the lungs; during the decrease in the thoracic capacity, the air passively flows out of the lungs. In both movements the lungs play an entirely passive part, their movements being determined by the pressure of air within them and by the thoracic walls, with which they are in close contact.

1. **Inspiration** is an active process, the result of muscle activity.
2. **Expiration** is a passive process, the result mainly of the recoil of the elastic tissue of the walls of the thorax and abdomen and of the elastic tissue of the lungs.

In inspiration the thorax is enlarged in all its diameters: viz., vertical, transverse, and antero-posterior. In expiration these diameters are in turn decreased as the thorax returns to its previous condition.

Inspiratory Muscles.—The muscles which from their origin, direction, and insertion contribute to the enlargement or expansion of the thorax are quite numerous, and include those muscles which enter into the formation of the thoracic walls (intrinsic muscles), as well as certain muscles which, having their origin elsewhere, are attached to the thoracic walls at different points (extrinsic muscles), though the extent to which they are called into activity depends on the necessity for either tranquil or energetic inspirations. The gradations between a minimum and a maximum inspiration are very slight, and it is difficult to state at what particular instant any given muscle begins to act. It is customary, however, to divide the muscles into two groups: (1) Those active in the average or ordinary inspirations, and (2) those active in maximum or extraordinary inspirations. Among the muscles active in ordinary inspirations may be mentioned the *diaphragm*, the *intercostales externi*, the *intercartilagenei*, the *levatores costarum*, the *scaleni*, and the *serratus posticus superior*. Among the muscles active in extraordinary inspirations may be mentioned, in addition to the foregoing, the *sterno-cleido-mastoideus*, the *trapezius*, and the *pectorales minor* and *major*.

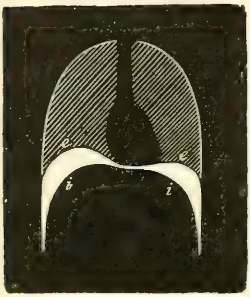


FIG. 191.—DIAGRAM SHOWING INTERVAL BETWEEN THE POSITION OF THE DIAPHRAGM IN EXPIRATION (*e*, *e*) AND INSPIRATION (*i*, *i*). THE INCREASE IN CAPACITY IS SHOWN BY THE WHITE AREAS.—(*Yeo.*)

The *vertical* diameter is increased by the contraction and descent of the *diaphragm*, and more especially of its lateral muscular portions. At the end of an expiration the diaphragm is relaxed, and the lower portion closely applied to the walls of the thorax. At the beginning of an inspiration the muscle-fibers contract, shorten, and approximate a straight line, whereby not only is the convexity of the diaphragm diminished, but that portion in contact with the thorax is drawn away, thus making a large free space into which the lateral and posterior portions of the lungs at once descend. The attachment of the central tendon of the diaphragm to the pericardium prevents any marked descent of this portion except in forcible inspiratory efforts (Fig. 191). The vertical diameters are thus enlarged, though unequally in different regions of the thorax.

As the diaphragm descends it displaces the abdominal viscera, forcing them downward against the abdominal walls, which advance and become more convex. In forcible inspiration the diaphragm, acting from the central tendon as the more fixed point, would draw the lower portion of the thorax inward were this not prevented by the outward pressure of the displaced viscera.

The *antero-posterior* and *transverse* diameters are increased by the elevation and outward rotation of the ribs and an advance of the sternum, both movements made possible by the construction and arrangement of the costo-vertebral and costo-chrondral and chrondrosternal articulations. The construction of these articulations is such as to permit at the first a slight elevation and depression of the head of the rib, and at the second a gliding of the tubercle on the transverse process. The axis around which the rib rotates practically coincides with the axis of the rib neck, which in the upper part of the thorax is almost horizontal, in the lower part somewhat sagittal in direction. Hence when the ribs are elevated the upper part of the thorax increases in its antero-posterior, the lower part in its transverse diameters. At the same time, the lower portion of the sternum is pushed forward and upward by the elevation of the anterior extremity of the ribs and the widening of the angle of the costo-chondral articulation. With the elevation of the ribs there goes an eversion or outward rotation

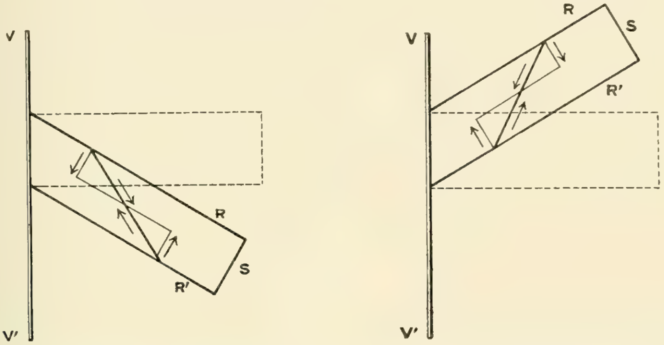


FIG. 192.—DIAGRAM ILLUSTRATING THE ACTION OF A, THE EXTERNAL INTERCOSTAL AND B, THE INTERNAL INTERCOSTAL MUSCLES. V, V′. Vertical support. R, R′. Parallel bars. S. Vertical strip, representing respectively the vertebral column, two ribs, and sternum.

which gives an additional increase to the transverse diameters. This elevation and outward rotation of the ribs is the resultant of the coöperation of the following muscles, viz.: the *intercostales externi*, the *intercartilagenei*, the *levatores costarum*, the *scaleni* and the *serratus posticus superior*.

The action of the *external intercostal* muscles has been a subject of much discussion. Some investigators have maintained that they are elevators of the ribs, and therefore inspiratory; others that they are depressors of the ribs, and therefore expiratory in function. At the present time the general consensus of opinion is that the former view is the one most in accordance with the facts. The situation of the muscles and the shortness of their fibers render it extremely difficult to obtain myographic tracings of their action. This is supposed, however, to be disclosed by the play of the apparatus suggested originally by Bernouilli, which consists, as shown in Fig. 192, of a vertical support carrying two freely movable parallel bars united at their outer extremities by a short vertical strip, representing respectively the vertebral column, two adjoining ribs, and a piece of the sternum.

The parallel bars are joined to each other by a short elastic band having the direction of and representing the external intercostal muscles. If the bars are depressed, the elastic band is elongated and made tense. On releasing the bars the band at once recoils and elevates them. Although the elastic force is the same in both directions, the bars are yet elevated for the reason that in accordance with the parallelogram of forces the component acting upward on the long arm of the lever preponderates over the component acting downward on the short arm of the lever. The action of the band is supposed to disclose and illustrate the action of the muscle.

The *intercartilaginei*, those portions of the intercostales interni which occupy the space between the costal cartilages from the sternum to their outer extremity, bear the same relation to the cartilages in reference to the sternum that the external intercostals bear to the ribs in reference to the vertebral column; that is, the point of attachment to the cartilage above, lies nearer the sternum, nearer the fulcrum, than the point of attachment below. Hence the same action is attributed to them as to the external intercostals: viz., elevation of the cartilages and the anterior extremities of the ribs.

The *levatores costarum*, as is evident from their points of origin and insertion, elevate the ribs posteriorly.

The *scaleni* muscles, *anticus*, *medius*, and *posticus*, arise from the transverse processes of the cervical vertebræ, and after pursuing a downward and forward direction are inserted into the sternal end of the first and second ribs. The action of the first two, at least, is to elevate the first rib and thus establish a fixed point from which the intercostal muscles can act. The posticus has doubtless a similar action on the second rib.

The *serratus posticus superior*, a quadrilateral sheet of muscle-fibers, arises mainly from the spines of the last cervical and first and second thoracic vertebræ. The anterior extremity is serrated and attached to the outer surfaces of the second, third, fourth, and fifth ribs beyond the angle. The action of the muscle is the elevation of the ribs to which it is attached.

In *forcible* or *extraordinary* inspirations, whereby the capacity of the thorax is still further increased, the foregoing muscles are reinforced by the *sterno-cleido-mastoideus*, the *trapezius*, and the *pectorales minor* and *major*. Their functions will become apparent from a consideration of their origins and insertions.

Expiratory Forces and Muscles.—Expiration, as previously stated, is a passive process brought about by the recoil of the elastic tissues of the thoracic and abdominal walls, and of the lungs, all of which have been stretched and made tense during inspiration. With the cessation of the inspiratory effort the elastic forces, assisted by the weight of the ribs, sternum, and soft tissues, return the thorax to its former condition. The result is a diminution of all the diameters of the thorax. The *vertical* diameter is diminished by the recoil of the tense abdominal walls, the replacement of the abdominal organs and the consequent ascent of the diaphragm to its former position. The *transverse* and *antero-posterior* diameters are diminished by the descent of the ribs, sternum, and lungs. It is somewhat uncertain if a normal expiratory movement necessitates active muscle contraction. If, however, there is any impairment of the elasticity of the lungs or ribs, or any interference with the free exit of the intra-pulmonary air, it is highly probable that the elastic forces are assisted by the internal intercostal and triangularis sterni muscles.

The action of the *internal intercostals* is less clearly understood than that of the externals, and for the same reasons. If, however, Bernouilli's model discloses the action of the latter, it equally well discloses the action of the former. Thus, if the parallel bars be joined by an elastic band having the direction of and representing the internal intercostals, and then forcibly elevated, the band is elongated and made tense. On releasing the bars, the elastic band at once recoils and depresses them. Here, again, though the elastic force is the same in both directions, the bars are depressed, for the reason that the component acting downward on the long arm of the lever preponderates over that acting upward on the short arm of the lever. The action of the band is supposed to disclose and illustrate the action of the muscle.

The *triangularis sterni* muscle, judging from its anatomic relations, in all probability assists in expiration by depressing the cartilages to which it is attached and as a further result the anterior extremities of the ribs.

After the elastic forces have ceased to act and the normal expiratory movement has been brought to a close, the thorax can be, to a considerable extent, still further diminished in all its diameters by the contraction, through volitional effort, of abdominal and thoracic muscles. To this decrease in the capacity of the thorax, as a result of which a much larger volume of air is expelled from the lungs than during passive expiration, the term *forced* expiration has been given. With the cessation of muscle activity the elastic forces of the now-compressed thoracic walls, aided by the return of upward displaced abdominal organs, at once restore the thoracic walls to the position they had attained at the end of passive expiration. Of the muscles active in *forced* expiration in addition to the intercostales interni and the triangularis sterni, the following may be mentioned, viz.: the *abdominales*, the *serratus posticus inferior*, and the *quadratus lumborum.*

The *externus abdominis* arises by a series of muscle slips from the outer surface of the lower eight ribs. After pursuing an oblique direction downward and forward, the slips blend to form a single muscle, which is inserted mainly into the outer lip of the anterior half of the crest of the ilium and into the central abdominal tendon or aponeurosis.

The *internus abdominis* arises mainly from the anterior two-thirds of the inner crest of the ilium and the lumbar fascia. Its fibers pass upward and forward to be inserted into the cartilages of the last three ribs and into the central abdominal tendon.

The *rectus abdominis* arises from the crest of the pubes and is inserted above into the cartilages of the fifth, sixth, and seventh ribs, and occasionally into the ensiform cartilage.

The *transversalis* arises from the cartilages of the last six ribs, the lumbar fascia, and the anterior half of the crest of the ilium. After passing transversely across the abdomen, the fibers are inserted mainly into the linea alba.

The conjoint action of these muscles is to diminish the convexity of the abdominal walls and to exert a pressure on the abdominal organs. These, taking the line of least resistance, are forced upward against the inferior surface of the diaphragm, which in consequence becomes more strongly curved and ascends higher into the thorax. The vertical diameter of the thorax is thus diminished. Acting from the pelvis as a fixed point, these muscles will also draw downward and inward the lower end of the sternum and the lower ribs and diminish the antero-posterior and transverse diameters.

The *serratus posticus inferior* arises from the spines of the last two thoracic and first two lumbar vertebræ. The fibers pass upward to be inserted into the lower border of the last four or five ribs beyond the angle. Their action is to depress the ribs and assist in expiration.

The *quadratus lumborum* has a similar action on the last rib.

Movements of the Lungs.—As the thorax is enlarging in all its diameters during inspiration, through muscle activity, the lungs are correspondingly enlarging in all their diameters, by virtue of their distensibility, through the pressure of the air within them. The lungs must therefore move downward, outward and forward. That this is the case is made evident both by an examination of the lungs through an intercostal space after removal of the skin and intercostal muscles and by the methods of percussion. The inferior border of each lung descends from the lower border of the sixth to the eleventh rib, inserting itself into the space developed between the thorax and diaphragm as the latter contracts and is drawn away from the former. In consequence of the lateral expansion the anterior border of each lung advances toward the middle line until the heart is almost covered. With the beginning and continuance of expiration the lungs exhibit a reverse movement which continues until they reach their original position. At all times, however, the movements of the lungs are entirely passive and determined by the movements of the thorax.

The succession of events in the thorax at the time of a respiratory act may be summarized as follows:

During Inspiration.

1. Enlargement of the thoracic diameters by muscle action.

2. Expansion of intra-pulmonary (alveolar) air.
3. Expansion of the lungs.
4. Lowering of the intra-pulmonary air pressure below the atmospheric air pressure.
5. Increase in the negativity of the intra-thoracic pressure.
6. Inflow of atmospheric air, in consequence of its higher pressure, until the intra-pulmonary air pressure rises to that of the atmosphere.

During Expiration.

1. Diminution of the thoracic diameters by the action of elastic forces.
2. Recoil of the lungs.
3. Compression of the intra-pulmonary (alveolar) air.
4. Rise of intra-pulmonary air pressure above the atmospheric air pressure.
5. Decrease in the negativity of the intra-thoracic pressure.
6. Outflow of intra-pulmonary air, in consequence of its higher pressure, until the intra-pulmonary air pressure falls to that of the atmosphere.

Respiratory Movements of the Upper Air-passages.—The resistance to the entrance of air into and through the respiratory tract is much diminished by respiratory movements of the nares and larynx which are associated and occur synchronously with the movement of the thorax.

The nares at each inspiration are dilated by the outward movement of their alæ or wings, the result of muscle activity. At each expiration they are diminished by the return of their cartilages through the play of elastic forces. The larynx, as shown by observation with the laryngoscope, exhibits corresponding movements of the vocal membranes. Their introduction at this level naturally narrows the tract, and would interfere with both the entrance and the exit of air were they not kept widely asunder during the time they are not required for purposes of phonation. This is accomplished by the tonic contraction of the posterior crico-arytenoid muscles, which are entirely respiratory in function.

It is not infrequently stated that these membranes exhibit considerable oscillations, outward and inward, corresponding to the periods of inspiration and expiration. The statements of the majority of laryngologists do not favor this view. During tranquil breathing the membranes are widely separated and almost stationary, seldom moving in either direction more than a few millimeters. In labored respirations these movements are naturally increased in extent. The irregular movements of the membranes occasioned by the unskilful use of the laryngoscope, especially with nervous patients, are not to be regarded as strictly physiologic. The respiratory space in quiet breathing is an isoceles triangle, with a length of 20 mm. and a width at the base of 15.5 mm. with an area of 155 mm.

Respiratory Types.—Observation of the respiratory movements in the two sexes shows that while the enlargement of the thoracic cavity is accomplished both by the descent of the diaphragm (as shown by the protrusion of the abdomen) and the elevation of the thoracic walls, the former movement preponderates in the male, the latter in the female, giving rise to what has been termed in the one case the *diaphragmatic* or *abdominal* and in the other the *thoracic* or *costal type* of respiration. The cause of this greater mobility and actvity of the thorax in the female has been a subject of much discussion. It has been attributed, on the one hand, to the necessity for a physiologic adjustment between respiration and child-bearing, and therefore a specific sex peculiarity; on the other hand, it has been attributed to persistent constriction of the waist, in consequence of which the full play of the diaphragm is prevented and the burden of inspiration is thrown on the thoracic muscles. It has been assumed that if inspiration were confined in women to the diaphragm, there would arise in the latter stages of gestation such an increase in intra-abdominal pressure that not only would respiratory exchanges be interfered with, but fetal life might be unfavorably influenced, if not endangered. Modern investigations have not confirmed this assumption, but, on the contrary, have corroborated the view that the preponderance of thoracic movement is due to the influences of dress restrictions, for with their removal the so-called costal type of breathing entirely disappears. While gestation may lead to a greater activity of the thorax, this is but temporary, for with its termination there is a return to the diaphragmatic type of breathing.

Number of Respirations per Minute.—The number of respirations which occur in a unit of time varies with a variety of conditions, the most important of which is age. The results of the observations of Quetelet on this point, which are generally accepted, are as follows:

Age.	Respirations per Minute.	Age.	Respirations per Minute
0– 1 year,	44	20–25 years,	18.7
5 years,	26	25–30 “	16.0
15–20 “	20	30–50 “	18.0

From these observations it may be assumed that the average number of respirations in the adult is eighteen per minute, though varying from moment to moment from sixteen to twenty. During sleep, however, the respiratory movements often diminish in number as much as 30 per cent., at the same time diminishing in depth.

Rhythm.—Each respiratory act takes place normally in a regular methodic manner, each event occurring in a definite sequence and occupying the same relative period of time. This rhythm, however, is not infrequently temporarily disturbed by emotions, volitional acts, muscle activity, phonation, changes in the composition of the blood, etc.; with the removal of these disturbing factors, the respiratory mechanism soon returns to its normal condition.

A graphic representation of the excursions of the thoracic walls, rhythmic or otherwise, is obtained by fastening to the thorax an apparatus, a *stethometer* or a *pneumograph*, which by means of a tambour takes up and transmits the movement to a second tambour provided with a recording lever. A simple form of pneumograph, suggested by Fitz (Fig. 193), consists of a coil of wire two and a half centimeters in diameter and about 40 centimeters in length, enclosed by thin rubber tubing, one end of which is closed, the other placed in communication with either a tambour and lever or with a piston recorder. By means of an inelastic cord or chain the apparatus is securely fastened to the chest. With each inspiration the spring is elongated, the air within the system is rarefied, and as a result the lever falls; with each expiration the reverse conditions obtain and the lever rises. If the lever be applied to the recording surface of a moving cylinder, a curve of the thoracic movement, a *pneumatogram*, is obtained (Fig. 194), from which it is apparent that inspiration takes place more abruptly and occupies a shorter period of time than expiration; that expiration immediately follows inspiration, but that there is a slight pause between the end of the expiration and the beginning of the inspiration. The time relations of the two movements can be obtained by a magnet-signal actuated by an electric current interrupted once a second. The ratio of inspiration to expiration has been represented as 5 to 6, or 6 to 8.

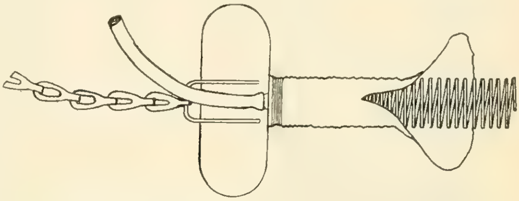


FIG. 193.—PNEUMOGRAPH.—(*Fitz.*)

Volumes of Air Breathed.—The volumes of air which enter and leave the lungs with each inspiration and expiration naturally vary with the extent of the movement, though four at least may be determined: (1) that of an ordinary inspiration; (2) that of an ordinary expiration; (3) that of a forced inspiration; (4) that of a forced expiration.

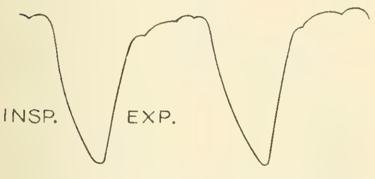


FIG. 194.—A PNEUMATOGRAM.—(*After Marey.*)

The apparatus employed for the determination of these different volumes is the *spirometer*, a modification of the gasometer. The form introduced by Jonathan Hutchinson (Fig. 195) consists of two metallic cylinders, one (a) containing water, the other (b) containing air, the latter being inserted into the former. The air cylinder is balanced by weights so accurately that it remains stationary in any position. A tube, penetrating the base of the water cylinder, is continued upward through and above the level of the water. The air-space above is thus placed in free communication with the external air. A stopcock at the outer end of this tube prevents the escape of the air when this is not desirable. To the free end of the tube a rubber tube provided with a suitable mouthpiece is attached, through which air can be breathed into or out of the air cylinder. With each inspiration the air cylinder descends; with each expiration it ascends. A scale, on one of the side supports, graduated in cubic inches or centimeters, indicates the volume of air inspired or expired.

With this apparatus Hutchinson, from a long series of observations, defined and determined the above-mentioned four volumes as follows:

1. The *tidal* volume, that which flows into and out of the lungs with each inspiration and expiration, which varies from 20 to 30 cubic inches (312 to 468 c.c.).
2. The *complemental* volume, that which flows into the lungs, in addition to the tidal volume, as a result of a *forcible inspiration*, and which amounts to about 110 cubic inches (1748 c.c.).
3. The *reserve* volume, that which flows out of the lungs, in addition to the tidal volume, as a result of a *forcible expiration*, and which amounts to about 100 cubic inches (1562 c.c.).

   After the expulsion of the reserve volume there yet remains in the lungs an unknown volume of air which serves the mechanic function of distending the air-cells and alveolar passages, thus maintaining the conditions essential to the free movement of blood through the capillaries and to the exchanges of gases between the blood and alveolar air. As this air can not be displaced by volitional effort, but resides permanently in the alveoli and bronchial tubes though constantly undergoing renewal, it was termed—
4. The *residual* volume, the amount of which is difficult of determination, but has been estimated by different observers at 914 c.c., 1562 c.c., 1980 c.c.

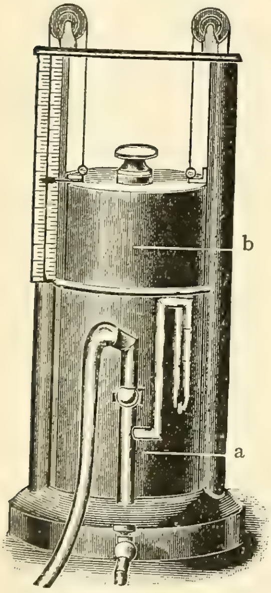


FIG. 195.—SPIROMETER.—(*Hutchinson.*)

The Vital Capacity of the Lungs.—From foregoing statements it is clear that the thorax and lungs are capable of a maximum degree of expansion, at which moment the lungs contain their maximum volume of air. This volume, whatever it may be, represents the entire capacity of the lungs in the physiologic condition, and includes the tidal, the complemental, the reserve, and the residual volumes. Mr. Hutchinson, however, defined the vital or respiratory capacity of the lungs as the amount of air which can be expelled by the most forcible expiration after the most forcible inspiration, and which therefore *excludes* the residual volume. The vital capacity was supposed to be an indication of an individual's respiratory power, not only in physiologic but also in pathologic conditions. Though averaging about 230 cubic inches (3593 c.c.) for an individual 5 feet 7 inches in height, the vital capacity varies with a number of conditions, the most important of which is stature. It is found that between 5 and 6 feet the capacity increases 8 inches (125 c.c) for each inch increase in height.

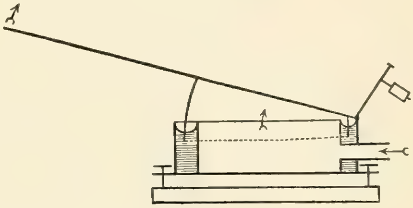


FIG. 196.—PNEUMATOGRAPH.—(*Gad.*)

The volume changes of the thorax indicated by the volumes of air entering and leaving the lungs can be not only determined but graphically represented by means of an apparatus similar in principle to the spirometer, devised by Gad and known as the *pneumatograph* or *aëroplethysmograph* (Fig. 196). This consists of a quadrangular box with double walls, the space between which is filled with water. The center of the box is an air chamber. A thin-walled mica box sinks into the water. Posteriorly it is attached to and rotates around an axis, which permits of an elevation or depression of the anterior portion. It is also carefully counterpoised. A light lever attached to the mica box records its movements. The interior of the box communicates by a tube with a large reservoir into which the individual breathes, the object being to prevent a too rapid vitiation of the air. Inspiration causes the lever to descend, expiration to ascend. Previous graduation of the apparatus is necessary to determine the volumes breathed. A graphic record of the volume changes is shown in Fig. 197.

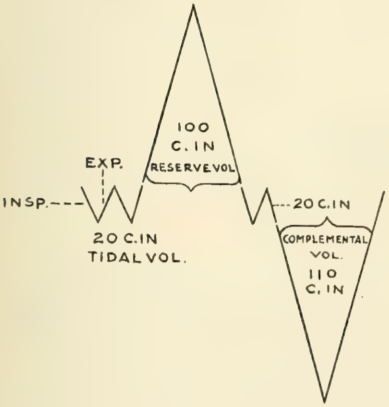


FIG. 197.—REPRESENTING THE VOLUME CHANGES OF THE THORAX AND LUNGS (DIAGRAMMATIC).

Respiratory Sounds.—On applying the ear over the trachea and bronchi there is heard during both inspiration and expiration a well-defined sound, loud, harsh, and blowing in character, which from its situation is known as the *bronchial* sound. It is especially well heard between the scapulæ above the fourth dorsal vertebra. This sound is produced in the larynx, for with its separation from the trachea the sound disappears. The cause of the sound is to be found in the narrowing of the air-passage at the level of the vocal membranes, though the mechanism of its production is uncertain. On applying the ear to almost any portion of the chest-wall, but especially to the infrascapular area, there is heard during both inspiration and expiration a delicate, sighing, rustling sound, which from its supposed seat of origin, the air-vesicles or -cells, is known as the *vesicular* sound. This sound is supposed to be due to the sudden expansion of the air-cells during inspiration and to the friction of the air in the alveolar passages.

THE CHEMISTRY OF RESPIRATION.

The general nutritive process as it takes place in the tissues involves the assimilation of oxygen and the evolution of carbon dioxid. The former is the first, the latter the last, of a series of chemic changes the continuance of which is essential to the maintenance of all life phenomena. A constant supply of oxygen and an equally constant removal of carbon dioxid are necessary conditions for tissue activity. The respiratory movements constitute the means by which the oxygen of the air is brought into, and the carbon dioxid expelled from, the lungs into the surrounding air. The blood is the medium by which the oxygen is transported from the lungs to the tissues and the carbon dioxid from the tissues to the lungs.

The exchanges between blood and tissues constitute *internal* respiration, in contradistinction to the thoracic movements by which the air is brought into relation with the blood, and which constitute *external* respiration. The transfer of the oxygen by the blood from the interior of the lungs to the tissues, and of the carbon dioxid from the tissues to the interior of the lungs, is the outcome of a series of chemic changes which are related to the exchange of gases between the air in the lungs and the blood, on the one hand, and between the blood and tissues, on the other.

In consequence of the many and complex chemic changes which attend these gaseous exchanges, there arise changes in composition of:

1. The air breathed.
2. The blood, both arterial and venous.
3. The tissue elements and the lymph by which they are surrounded.

The investigation of the nature of these changes, the mechanism of their production, and their quantitative relations constitutes the subject-matter of the chemistry of respiration.

CHANGES IN THE COMPOSITION OF THE AIR.

Experience teaches that the air during its sojourn in the lungs undergoes such a change in composition that it is rendered unfit for further breathing. Chemic analysis has shown that this change involves a loss of oxygen, a gain in carbon dioxid, watery vapor and organic matter. For the correct understanding of the phenomena of respiration it is essential, that not only the character but the extent of these changes be known. This necessitates an analysis of both the inspired and expired airs, from a comparison of which certain deductions can be made.

The results which have been obtained are represented in the following table:

Inspired Air.

100 vols.	Oxygen,	20.80.
	Carbon dioxid,	traces.
	Nitrogen,	79.20.
	Watery vapor,	variable.

Expired Air.

100 vols.	Oxygen,	16.02.
	Carbon dioxid,	4.38.
	Nitrogen,	79.60.
	Watery vapor,	saturated.
	Organic matter.	

These analyses indicate that under ordinary conditions the air loses oxygen to the extent of 4.78 per cent. and gains carbon dioxid to the extent of 4.38 per cent.; that it gains in nitrogen to the extent of 0.4 per cent. and in watery vapor from its initial amount to the point of saturation, as well as in organic matter. It is to these changes in their totality that those disturbances of physiologic activity are to be attributed which arise when expired air is re-breathed for any length of time without having undergone renovation.

Special forms of apparatus have been devised for the collection and analysis of gases. Their construction as well as the methods of analysis involved are complicated and need not be described in this connection. The presence of the carbon dioxid, however, may be readily shown by breathing through a glass tube into a vessel containing barium or calcium hydrate. The turbidity which immediately follows is due to the formation of barium or calcium carbonate, which can be due only to the presence of carbon dioxid. That this turbidity is not due to the carbon dioxid normally present in the air is shown by the fact that the solution remains clear until the passage of the atmospheric air has been maintained for some time. From the percentage loss of oxygen and gain in carbon dioxid, the total oxygen absorbed and carbon dioxid exhaled may be approximately calculated. Thus, if the volume of air breathed daily be accepted at either 10,800 or 12,240 liters, and the percentage loss of oxygen be 4.78, the total oxygen absorbed may be obtained by the rule of simple proportion, *e. g.*:

$$100 : 4.78 :: 10,800 : x = 516 \text{ liters}$$

Or

$$100 : 4.78 :: 12,240 : x = 585 \text{ liters.}$$

By the same method the total carbon dioxid exhaled is found to be either 473 or 526 liters; volumes in both instances which agree very well with volumes obtained by other methods.

From the fact that when one volume of oxygen combines with carbon it gives rise to but one volume of carbon dioxid, it is evident that of the oxygen absorbed the greater portion by far is utilized in the oxidation of the carbon, while the smaller portion is utilized in the oxidation of other substances, but especially hydrogen, as shown by the increase in water eliminated beyond that consumed. These amounts, however, are not fixed but variable, and depend on the quality and quantity of the foods, exercise, etc. The ratio of the volume of the carbon dioxid exhaled to the volume of oxygen absorbed is known as the respiratory quotient, and is usually represented by the symbol $\frac{CO_2}{O}$. Thus in the foregoing analysis the respiratory quotient is 0.916.

The gain in nitrogen is a variable factor, ranging from zero to 0.9 per cent. This gain is probably of accidental occurrence, due to absorption from the large intestine, in which decomposition of nitrogen-holding compounds is taking place. It is generally believed that free nitrogen plays no part in any phenomenon of combination or decomposition within the body.

The gain in watery vapor will depend on the amount previously present in the air. This is conditioned by the temperature. With a rise in temperature the percentage of water increases; with a fall, it decreases. By breathing into a vessel containing pumice stone saturated with sulphuric acid, the vapor may be collected. The difference observed between the weight before and after breathing is an indication of the amount by weight of water exhaled during the time of breathing. It has been calculated that the amount of water exhaled daily approximates 500 grams. Though invisible at ordinary temperatures, it becomes visible at low temperature as soon as it emerges from the respiratory tract. The loss of heat is followed by a condensation of the vapor, which appears at once as a cloudy precipitate.

The gain in organic matter is also variable. The amount present is not sufficient to permit of a thorough chemic analysis, but there are reasons for believing that it belongs to the proteid group of bodies. If it accumulates in the air, especially at high temperatures, it readily undergoes decomposition, with the production of offensive odors. Traces of free ammonia have also been found in the expired air. In addition to these chemic changes, the air experiences physical changes; *e. g.*, a rise in temperature and an increase in volume. The rise in temperature can be shown by breathing through a suitable mouthpiece into a glass tube containing a thermometer. By this means it has been shown that inspired air at 20° C. rises in temperature to 37° C.; at 6.3° to 29.8° C. The increase in the temperature will depend upon that of the air inspired and the time it remains in the lungs. If retained a sufficient length of time it will always become that of the body. As a result of the heat absorption the expired air increases in volume about one-ninth over that of the inspired air. When corrected for temperature and pressure and freed from aqueous vapor, the volume of the expired air is less than that of the inspired air by about one-two hundred and fiftieth.

The Composition of the Alveolar Air.—The foregoing statement of the composition of the expired air, derived in part from the upper air-passages, trachea, and bronchi, does not necessarily represent the composition of the alveolar air. It is very probable that the percentage of carbon dioxid is greater, the percentage of oxygen less, in the latter than in the former. This is made evident by collecting in several portions the expired air as it escapes from the respiratory tract and subjecting it to analysis. The last portion always contains a larger amount of carbon dioxid and a smaller amount of oxygen than the first portion. The determination of the composition of the alveolar air is extremely difficult. It has been estimated to contain from 5 to 6 per cent. of carbon dioxid and from 14 to 18 per cent. of oxygen.

Pulmonary Ventilation.—It is owing largely to this inequality of volumes and consequently of the "partial pressures" of these two gases in the trachea and alveoli that the degree of ventilation necessary for the exchange of gases between lungs and air is maintained. Though the respiratory movements doubtless create currents in the air-passages which carry, on the one hand, a portion of the inspired air directly into the alveoli, and, on the other hand, carry a portion of the alveolar air directly out of the body, other portions find their way into and out of the alveoli in accordance with the laws of diffusion. If the pressure of the oxygen in the trachea is 158 mm. Hg. and in the alveoli approximately 122 mm. Hg., diffusion downward will take place. Equilibrium, however, is never established, as the oxygen is continually disappearing by passing into the blood. On the contrary, if the carbon dioxid pressure in the alveoli is approximately 28 to 40 mm. Hg., and in the trachea 0.3 mm. Hg., diffusion will take place upward. Equilibrium will never be established, however, as the carbon dioxid is constantly coming out of the blood. Pulmonary ventilation may also be aided by those alternate changes in volume of the heart, great vessels, and lungs occurring as the result of the heart-beat and producing the so-called cardio-pneumatic movements.

CHANGES IN THE COMPOSITION OF THE BLOOD.

The blood which flows into the lungs through the pulmonary artery is dark bluish-red, that which flows from the lungs into the pulmonary veins is scarlet red, in color. The blood is changed, while flowing through the lung capillaries, from the venous to the arterial condition. As the air in the lungs gains carbon dioxid and loses oxygen, it is fair to assume that what the air gains the blood loses, and what the air loses the blood gains. In other words, the blood, while passing through the lungs, is changed from venous to arterial by the loss of carbon dioxid and the gain of oxygen. The change in color of venous blood from dark bluish to scarlet red is strikingly shown by shaking it in a test-tube with oxygen or atmospheric air.

The blood which flows into the tissues through the arteries is red, that which flows from the tissues into the veins is bluish, in color. The blood while flowing through the tissue capillaries is changed from the arterial to the venous condition. Since arterial blood when deprived of oxygen becomes bluish-red, the indication is that the change in color is associated with, if not entirely due to, the escape of oxygen into the tissues. The constant elimination of carbon dioxid from the blood into the lungs indicates that the carbon dioxid is as constantly passing from the tissues through the capillary walls into the blood.

These considerations are confirmed by the results of analyses which have been made of both venous and arterial blood. The presence of gas in the blood is demonstrated by subjecting it under appropriate conditions to the vacuum of the mercurial air-pump, into which it at once escapes. From 100 volumes, an average of 60 volumes of gas at standard pressure, 760 mm. Hg. and temperature 0° C., can thus be obtained.

Gases of the Blood.—An analysis of the volumes of gas removed from both venous and arterial blood shows that each consists of oxygen, carbon dioxid, and nitrogen, though in different amounts. An average composition of the gases extracted from dog's blood obtained from the right ventricle and carotid artery is given in the following table:

Venous blood 100 vols.	Oxygen, ...	9–12 vols.	Arterial blood 100 vols.	Oxygen, ...	20 vols.
	Carbon dioxid,	45 "		Carbon dioxid,	40 "
	Nitrogen, ...	1– 2 "		Nitrogen, ...	1– 2 "

The changes produced in the blood by respiration, both external and internal, become apparent from a comparison of these analyses. The venous blood while passing through the lungs gains from eight to eleven volumes per cent. of oxygen and loses five volumes per cent. of carbon dioxid. The arterial blood while passing through the tissues loses oxygen and gains carbon dioxid in corresponding amounts. The volume of nitrogen is not appreciably changed.

The Relation of the Gases in the Blood.—The mechanism by which the gases become associated with the blood at the moment of their entrance into it, and again become dissociated just prior to their exit from it, as well as their relation to the blood while in transit, will be more readily understood after reference to a few elementary facts relative to the absorption of gases by liquids in general and the conditions of temperature and pressure by which it is influenced.

It is well known that liquids will absorb or dissolve at any constant pressure unequal volumes of different gases in accordance with their solubilities and with variations in temperature. Water, for example, will absorb, in accordance with the foregoing conditions, oxygen, carbon dioxid and nitrogen, as well as many other gases. The volume of any gas thus absorbed is known as the *coefficient of absorption,* and may be defined as the number of cubic centimeters of the gas which one cubic centimeter of water will absorb when the gas, in contact with the water, stands under a pressure of one atmosphere or 760 mm. of mercury and at a temperature of 0° C. The volume absorbed, however, varies inversely as the temperature. Thus at 0° C. the volume of oxygen absorbed by one volume of water is 0.0489 c.c.; of carbon dioxid 1.713 c.c.; of nitrogen 0.0234 c.c. With a rise of temperature, the pressure remaining constant, the absorptive power of water for each of these gases diminishes. Thus at 15° C., the volumes of oxygen, carbon dioxid and nitrogen absorbed are 0.0310 c.c., 1.0025 c.c. and 0.0168 c.c. respectively. Though the volume of the gas absorbed diminishes as the temperature rises, it is independent of pressure, for no matter to what extent the pressure may vary the *volume* absorbed is always the same. (Law of Henry.)

If the *weight* of the gas absorbed be considered rather than the volume (that is the product of the volume and the density or the number of molecules in the volume), then the temperature remaining constant, the weight of the volume absorbed increases and decreases proportionately as the pressure rises and falls. Thus at a pressure of 760 mm. of mercury and at a temperature of 0° C., the volume of oxygen absorbed by one volume of water is 0.0489 c.c.; at 1520 mm. of mercury, the *same volume* is absorbed but its *weight* is doubled. If the pressure falls below 760 mm. of mercury the *same volume* is absorbed but its weight is diminished. (Law of Dalton.) Because of the foregoing facts, it is necessary in all gaseous determinations to reduce for purposes of comparison the obtained volumes to standard temperature (0° C.) and pressure (760 mm. of mercury).

When the liquid is once saturated with a gas at a constant pressure and temperature, there is coincidently with the entrance of the gas into the liquid, an equivalent exit of the gas from it, though the volume retained in the liquid remains constant. The reason for this fact is, that under the conditions, the volume of the gas dissolved by the liquid though *small in amount* exerts a pressure in the opposite direction equivalent to the pressure acting upon the liquid. If one cubic centimeter of water absorbs 0.0489 c.c. of oxygen at 760 mm. and 0° C., this volume will exert a pressure opposite in direction of 760 mm. of mercury. For this reason the entrance and exit of the gas are equal and opposite.

If water be exposed to atmospheric air consisting of oxygen, carbon dioxid, and nitrogen in the ordinary proportions, at any given temperature and pressure, the water will absorb unequal volumes of each of the three gases. The pressure under which each gas is absorbed is a part only, however, of the total atmospheric pressure at the time. The pressure exerted by any one of these gases is known as its "partial pressure," and depends on the percentage volume of the gas present. If atmospheric air contains at standard pressure and temperature 79.15 volumes per cent of nitrogen, its partial pressure will be $\frac{79.15}{100}$ of 760, or 601.54 mm. Hg.; if the air contains 0.04 volume per cent. of carbon dioxid and 20.85 volumes per cent. of oxygen, the partial pressure of each will be 0.30 mm. Hg. and 158.46 mm. Hg. respectively. The absorption of each gas is independent of all the rest, and is the same for nitrogen, for example, as if it alone were present at a pressure of 601.54 mm. Hg.

Again, if water holding in solution a certain volume of a gas—carbon dioxid, for example—be exposed to an atmosphere containing but 0.04 volume per cent. of carbon dioxid, and having therefore a pressure of but 0.3 mm. Hg., the gas will at once begin to leave the water, and continue to do so until the pressure of the carbon dioxid in the atmosphere balances the pressure of the gas in the water, at which moment the escape of the gas ceases. The pressure of a gas in a liquid is equal to that pressure in millimeters of mercury of the same gas in the atmosphere which is required to keep it in solution. What is true for the carbon dioxid is true for any other gas that may be in solution. If a liquid has a greater density than water as from the presence of inorganic salts, the absorptive power under standard conditions of temperature and pressure becomes less. It is for this reason that blood-plasma contains less oxygen, nitrogen and carbon dioxid than water.

It will be recalled that the blood yields up its gases when subjected to the vacuum of the mercurial pump; that is, to a diminution or complete removal of the atmospheric pressure. From this it might be inferred that the gases are merely held in solution by pressure, and at once escape the moment they are exposed to a space in which there is a very slight or a total absence of pressure. In other words that the absorption of gases by the blood and their escape from it follows the law of pressure as stated in foregoing paragraphs. It is therefore necessary to test this supposed condition of the gases in the blood by subjecting the latter to gradually diminishing pressures, with a view of determining in how far the discharge of the gases follows the law of falling pressures. For convenience the conditions of each gas will be considered separately.

Oxygen.—If blood is subjected to a succession of pressures progressively less than the standard, it is found that though oxygen is evolved, its evolution is not in accordance with the law of partial pressures; that is, in proportion to the diminution of pressure. Within wide limits—*e. g.*, from 760 to 332 mm. atmospheric pressure, to which correspond oxygen pressures of 160 and 70 mm. respectively—there is but a slight increase in the amount of oxygen evolved; and it is not until the pressure of the oxygen falls below this that it begins to be liberated in large amounts. From this on, the oxygen continues to be liberated with decreasing pressures, until the zero point is reached, when all gaseous discharge ceases. Coincidently the blood changes in color from a bright red to a deep bluish-red. It is evident from the results of this procedure that the condition of the oxygen in the blood is but to a slight extent one of physical absorption. The indications are that the union is of the nature of a chemic combination.

If the red corpuscles are removed from the blood and the plasma alone treated in the manner above described, it will be found that the oxygen liberated now follows the law of partial pressure. The amount so liberated, however, is small—about one per cent. of the total oxygen of the blood. The agent therefore which holds the oxygen in combination is the red corpuscle, and more especially the hemoglobin, which constitutes about 30 per cent. of its volume. This is proved by the fact that a solution of gas-free hemoglobin of a strength equivalent to that of the blood (14 per cent.), exposed to oxygen under a gradually increasing pressure from zero up to 50 to 70 mm. pressure, will absorb large quantities of oxygen; beyond this point the amount absorbed is again small in comparison. At 70 mm. pressure the hemoglobin is almost saturated. Coincidently with this absorption the hemoglobin changes in color from dark blue to bright red; changes from hemoglobin to oxyhemoglobin. The reverse method, that of subjecting oxyhemoglobin to gradually diminishing pressures, yields opposite results, that is the oxygen becomes dissociated and the force by which this is accomplished is known as the force of dissociation. As one gram of hemoglobin combines with 1.59 c.c. of oxygen, and as the percentage of hemoglobin is 13.50 to 14, it is evident that there is sufficient hemoglobin to combine with practically all the oxygen usually present in the blood.

The union of the oxygen with the hemoglobin is therefore largely chemic in character, dependent however on pressure. About one-half of one per cent. is physically absorbed by or dissolved in the plasma; the remainder is chemically combined with the hemoglobin.

The association or combination of oxygen is favored by a pressure of at least from 30 to 50 mm. Hg. and upward; the dissociation, by diminution of pressure. In the conversion of hemoglobin into oxyhemoglobin two antagonistic forces are at work, heat and chemic affinity. The former endeavors to prevent, the latter to favor, the union. Chemic affinity increases with the influence of mass, that is, in proportion to the number of atoms in a unit of volume, with the density and with the partial pressure of the oxygen. Diminution of pressure reduces the mass influence and permits the heat to bring about dissociation (Bunge). The following table by Hüfner shows the relative proportion of hemoglobin and oxyhemoglobin in blood containing 14 per cent. hemoglobin and exposed to air at gradually diminishing pressures:

ATMOSPHERIC PRESSURE IN MM. Hg.	PARTIAL PRESSURE OF OXYGEN IN MM. Hg.	HEMOGLOBIN PERCENTAGE.	OXYHEMOGLOBIN PERCENTAGE.
760	159.3	1.49	98.51
524.8	110	2.14	97.86
357.8	75	3.11	96.89
238.5	50	4.60	95.40
119.3	25	8.79	91.21
47.7	10	19.36	80.64
23.8	5	32.51	67.49
0.0	0.0	100.00	0.00

Carbon Dioxid.—The blood yields up its contained carbon dioxid to the vacuum of the gas-pump as completely as it does its oxygen. The same is not the case, however, if the red corpuscles are first removed and the experiment made with either plasma or serum. Even at zero pressure the fluid contains carbon dioxid, as shown by its liberation on the addition of some weak acid, as tartaric or phosphoric, an indication that it exists in a state of firm combination. The same result follows the addition of the red blood-corpuscles, which act in a manner similar to the acids just mentioned. This property of the corpuscles has been attributed to hemoglobin, and especially when in the state of oxyhemoglobin. It is for this reason that blood yields all its carbon dioxid to the vacuum of the gas-pump.

The limit of pressure at which the plasma ceases to physically absorb carbon dioxid and begins to chemically combine it is not very clearly defined. It has been estimated that of the entire amount, 38 to 45 volumes, only about 2.5 volumes are so absorbed, the remainder being in a condition of both loose and stable combination.

An analysis of the serum, and presumably of the plasma, shows the presence of sodium salts, with which the carbon dioxid could enter into combination, viz.: sodium carbonate and dibasic sodium phosphate. The sodium is thus partly divided between carbonic acid and phosphoric acid. The amount of the sodium which falls to carbon dioxid will depend on the mass influence of the latter; that is, its partial pressure.

At its origin in the tissues the carbon dioxid acquires a considerable tension, and its mass influence is correspondingly large. On entering the blood it combines with sodium carbonate, with the formation of sodium bicarbonate, as shown in the following equation:

$$Na_2CO_3 + CO_2 + H_2O = 2NaHCO_3.$$

At the same time, having a greater mass influence than the phosphoric acid, it will withdraw from the dibasic sodium phosphate one-half of its sodium, with the formation of sodium bicarbonate and monobasic sodium phosphate, as shown in the following equation:

$$Na_2HPO_4 + CO_2 + H_2O = NaHCO_3 + NaH_2PO_4.$$

With the diffusion of the carbon dioxid from the blood into the alveoli its tension in the venous blood falls, its mass influence diminishes, while that of the phosphoric acid relatively increases. As a result, the sodium is withdrawn from the sodium bicarbonate, an additional liberation of carbon dioxid takes place and dibasic sodium phosphate is re-formed. The association or combination of the carbon dioxid with the basic salts depends on its partial pressure; its dissociation in the lungs, on a diminution of pressure.

Nitrogen.—This gas exists in both arterial and venous blood in a state of solution. There is no evidence that it enters into combination with any other element.

Tension of the Gases in the Blood.—It will be recalled that a liquid holding in solution one or more gases will on exposure to an atmosphere composed of the same gases either give up or absorb volumes varying in amount and in accordance with their partial pressures until equilibrium is established. If the pressure of any one gas in the atmosphere is greater than the pressure of the same gas in the liquid, it is absorbed; if the pressure is less the gas is discharged. Knowing the pressure of the gases in percentages of an atmosphere, at the beginning and the end of an experiment, the original tension or pressure of the gases in the liquid can be easily calculated. On this principle various forms of apparatus known as *aërotonometers* have been devised by which the tension of the gases in the blood can be determined.

These appliances consist essentially of a glass tube containing oxygen, carbon dioxid and nitrogen in known amounts and tensions. The blood from an animal is then allowed to flow directly from an artery or vein into the tube. As it flows down its sides in a thin layer it presents a large surface to the action of the contained gases. In the aërotonometer of Fredericq the blood made non-coagulable by the injection of peptone is returned from the opposite extremity of the tube to the animal. This enables the experiment to be continued for an hour or more. A knowledge of the tensions of the blood gases is of interest, as it affords a clue to the mechanism by which the interchange takes place between the lungs and the blood, on the one hand, and the blood and tissues, on the other. The results, however, of different observers are not sufficiently in accord to permit of positive deductions.

In the well-known experiments of Strassburger, the tension of the oxygen in the arterial blood of the dog was found to be 29.64 mm. Hg., or 3.9 per cent. of an atmosphere, and in the venous blood 22.04 mm. Hg., or 2.9 per cent. The tension of the carbon dioxid in the venous blood was found to be 41.14 mm. Hg., or 5.4 per cent. of an atmosphere, and in the arterial blood 21.8 mm. Hg., or 2.8 per cent. Very different results have been obtained by Fredericq with the aërotonometer devised by him and by the employment of a method different from that of Strassburger. Thus he states that the oxygen tension in the pulmonary alveoli is 136 mm. Hg., or 18 per cent. of an atmosphere while in the arterial blood it is 106 mm. Hg., or 14 per cent.; while the carbon-dioxid tension in the tissues varies from 38 to 68 mm. Hg., or from 5 to 9 per cent. of an atmosphere; while in the venous blood it varies from 30 to 41 mm. Hg., or from 3.8 to 5.4 per cent. and in the pulmonary alveoli it is about 21 mm. or 2.8 per cent.

CHANGES IN THE COMPOSITION OF THE TISSUES AND LYMPH.

From previous statements the inferences can be drawn that the oxygen leaves the blood as the latter flows through the capillaries; that it passes through the capillary wall into the surrounding lymph and so to the tissue-cells; that it oxidizes food materials in the tissue-cells whereby the potential energy of the former is liberated as kinetic energy; that the carbon dioxid so evolved passes into the lymph and through the wall of the capillary into the blood.

While this is doubtless the case, the presence of free oxygen in the tissues can not be demonstrated by the usual methods of gas analysis. Only in the saliva and in the blood of the placental umbilical vein can it be shown that oxygen has directly passed through the capillary wall. For this reason it has been claimed by a few investigators that oxygen does not leave the blood, but that the field of its activity as an oxidizing agent is limited to the blood-current, where it meets with and oxidizes easily reducible substances entering from the tissues. On this view the potential energy of the food would be liberated by mere decomposition or cleavage in consequence of cell activity.

Nevertheless many facts from the fields of comparative physiology and physiologic chemistry combine to support the view that oxygen is absolutely necessary to the maintenance of the life of all tissue-cells. Though they will continue to manifest their characteristic activities—*e. g.*, contraction on the part of a muscle, secretion by a gland, the conduction of a nerve impulse by the nerve, etc.—for a variable length of time after oxygen is prevented from gaining access to them, nevertheless they will in due time die.

The necessity for oxygen on the part of the tissues and the avidity with which they absorb it, is shown by their power of reducing pigments such as alizarine blue. If this pigment be injected into the blood-vessels of an animal and the animal killed in about ten minutes, it will be found that while the blood exhibits a deep blue color the tissues present their usual colors. But after exposure to the air or to free oxygen the latter also acquire the characteristic blue color. The explanation offered for this fact is that the tissues in their need for oxygen absolutely extract it from the pigment, reducing it to a colorless compound, which, however, on exposure recombines with oxygen and regains the original color.

Though free oxygen can not be shown to be present in the tissues, there are many reasons for believing that it is continually passing into them by way of the lymph-stream. Its rapid disappearance would indicate that it is immediately utilized for the production of carbon dioxid (which is improbable on other grounds), or that the tissues possess a capacity for oxygen storage, of placing it in reserve under some combination or other, by which it can be securely retained until required for oxidation purposes. This is rendered probable from the fact that the carbon dioxid evolved at any given moment is not necessarily dependent on the oxygen just absorbed, for if oxygen be withheld from a nutritive fluid which is being artificially circulated through a recently isolated organ, carbon dioxid will continue to be discharged for some time. A muscle, or even a living animal—*e. g.*, a frog—placed in an atmosphere of pure nitrogen will remain active and evolve CO_2 for even several hours.

Naturally the absorption of oxygen and the discharge of carbon dioxid and the changes of composition which are incident to nutrition will be most marked in those tissues characterized by the greatest degree of physiologic activity. Muscle-tissue exhibits these changes to a greater degree than bone. Tissues with intermediate degrees of activity should exhibit corresponding degrees of respiratory change.

Experiment confirms this view. Thus, 100 grams each of muscle, spleen, and broken bone from a recently living animal exposed to the air for twenty-four hours absorbed respectively 50.8 c.c., 27.3 c.c., and 17.2 c.c. of oxygen, while each discharged during the same period 56.8 c.c., 15.4 c.c., and 8.1 c.c. of carbon dioxid respectively. In another series of experiments by a different observer 100 grams of muscle absorbed in three hours 23 c.c. of oxygen, and 100 grams of bone 5 c.c. of oxygen. Both tissues discharged carbon dioxid in amounts proportional to the oxygen absorbed. The same respiratory changes may be more satisfactorily demonstrated by passing blood through the tissues of isolated organs and the tissues of recently living animals. The analysis of the blood before and after perfusion shows a loss of oxygen and a gain in carbon dioxid.

Tension of the Gases in the Tissues.—As the presence of free oxygen can not be demonstrated, its tension there must be regarded as *nil*. The tension of the carbon dioxid is quite high, though difficult of exact determination. It has been estimated at from 45 to 68 mm. Hg., or from 6 to 9 per cent. of an atmosphere.

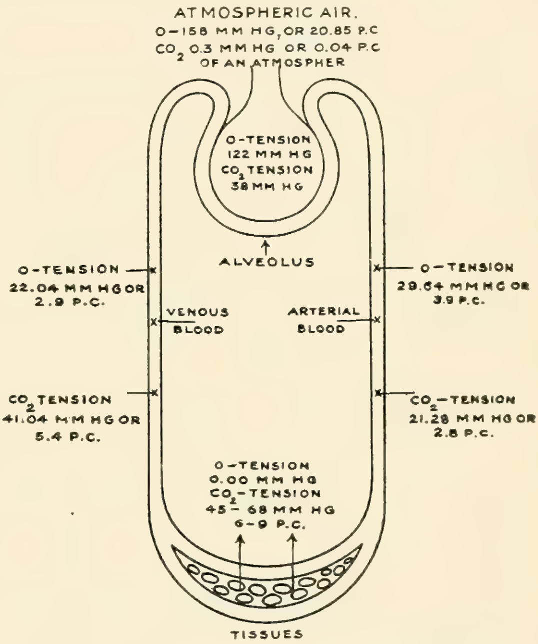

ATMOSPHERIC AIR.
O–158 MM HG, OR 20.85 P.C
CO_2 0.3 MM HG OR 0.04 P.C OF AN ATMOSPHER
O-TENSION 122 MM HG
CO_2 TENSION 38 MM HG
ALVEOLUS
O-TENSION 22.04 MM HG OR 2.9 P.C.
VENOUS BLOOD
ARTERIAL BLOOD
O–TENSION 29.64 MM HG OR 3.9 P.C.
CO_2 TENSION 41.04 MM HG OR 5.4 P.C.
CO_2–TENSION 21.28 MM HG OR 2.8 P.C.
O–TENSION 0.00 MM HG
CO_2–TENSION 45–68 MM HG 6–9 P.C.
TISSUES

Fig. 198.—Diagram showing the Relative Tension of Oxygen and Carbon Dioxid in the Lungs, in the Blood, and in the Tissues.

The variations of tension or pressure of these two gases in the lungs, in different parts of the vascular apparatus, and in the tissues, and their relations to each other, are shown in Figure 198, expressed in mm. Hg. and percentages of an atmosphere. The figures inserted are those of Strassburger and are of less value as far as the oxygen tension is concerned than those of Fredericq.

The Mechanism of the Gaseous Exchange.—In these pressure differences sufficient cause is found for the exchange of the gases. The oxygen pressure in the alveoli being in excess of that in the blood, the gas passes through the thin alveolo-capillary wall into the plasma. As the oxygen pressure in the plasma rises and approximates that in the alveoli, a portion of the oxygen combines with the hemoglobin until the latter is almost saturated. The corpuscle is then carried through the arterial system surrounded by oxygen under a definite pressure which is sufficient to keep the absorbed oxygen in union with the hemoglobin. On passing into the systemic capillaries, the blood enters a region in which the oxygen tension in the surrounding tissues is *nil*. At once the oxygen dissolved in the plasma passes through the capillary wall into the surrounding tissue-spaces. The pressure removed from the corpuscle, a dissociation of the oxygen and of the hemoglobin takes place, after which the oxygen also passes through the capillary wall into the surrounding lymph and so to the tissue-cells where it is stored and utilized. On passing into the venous system the dissociation of the oxygen and the hemoglobin is checked by the rise of oxygen pressure in the plasma. On reaching the lungs the oxygen again passes into the blood until the former condition is regained.

The sojourn of the blood in the capillaries being short, the oxyhemoglobin can part with but a portion of its oxygen, sufficient, however, to satisfy the needs of the tissues.

The carbon dioxid pressure in the tissues being in excess of that in the blood, it passes through the capillary wall into the blood, where it exists in the free and combined states. On passing into the pulmonic capillaries the blood enters a region in which the carbon dioxid in the alveoli is less than in the blood. At once a diffusion and dissociation of the carbon dioxid takes place through the alveolo-capillary wall until equilibrium is established. This, however, is of very short duration, for the carbon dioxid so eliminated is rapidly removed from the lungs by the respiratory movements.

While diffusion, in response to physical and chemic conditions, thus plays a large part in, and is sufficient to account for, the exchanges of gases, it is possible that the alveolar or respiratory epithelium may also play an essential rôle. It is believed by some investigators that it is active in both the absorption of oxygen and the excretion of carbon dioxid. This view has been suggested as a means of interpreting the results of the experiments of more recent investigators, made with a view of determining the tension of the blood gases. It was found by Bohr that the tension of the oxygen in arterial blood was often as high as 101 to 144 mm. Hg., and in many instances higher than the tension of the oxygen in the trachea, while the carbon dioxid tension in the trachea was higher than in the blood. Haldane and Smith by a different method found an oxygen tension in the arterial blood of 200 mm. Hg. If these results should prove to be correct, though they are at present subject to considerable criticism and not generally accepted, some other force than diffusion would have to be found to explain the facts. It would then remain to determine in how far the alveolar epithelium could be regarded as an active agent in both absorption and excretion in opposition to pressure.

THE TOTAL RESPIRATORY EXCHANGE.

The total quantities of oxygen absorbed and carbon dioxid discharged by a human being in twenty-four hours are measures of the intensity of the respiratory process, and an indication of the extent and character of the chemic changes attending all life phenomena. Their determination and their relation to each other are matters of interest and importance. The quantities which have been obtained by different observers are the outcome of calculations based on certain groups of data and of experiments made with special forms of apparatus.

Thus from the total air breathed daily, estimated from the amounts obtained during a longer or shorter period, of experiments with spirometric apparatus, and from the percentage loss of oxygen and gain of carbon dioxid shown by an analysis of the respired air, it can be calculated at least approximately what the total amounts of oxygen absorbed and carbon dioxid exhaled must be. If it be assumed that the minimum daily volume of air breathed is 10,800 liters and the maximum volume 12,240 liters, and the percentage loss of oxygen is 4.78, then the total volume of oxygen absorbed is 516 liters (735.17 grams) or 585 liters (836.42 grams). By the same method the total carbon dioxid exhaled daily is found to be either 473 liters (931.8 grams) or 526 liters (1036 grams). The direct experiments which have been made with specially devised forms of apparatus, both on human beings and animals, have yielded similar results. With those forms which are adapted for both human beings and animals—Scharling's, Pettenkofer and Voit's—it is only possible, however, to determine the amount of oxygen absorbed. This is done by deducting the loss in weight by the man or animal during the experiment from the combined weights of the carbon dioxid and water discharged. The difference represents the oxygen absorbed.

The Pettenkofer-Voit apparatus (Fig. 199) consists essentially of a chamber large enough to admit a man and capable of being made air-tight with the exception of an inlet for air for breathing purposes. The respired air is drawn through a tube and measured by a large meter turned by a water or gas motor. By means of a side tube a fractional quantity of the main column of air is diverted to an absorption apparatus by a small pump. This air first passes into a vessel containing H_2SO_4, by which the water is collected; then into long tubes containing barium hydroxid, by which the carbon dioxid is absorbed; thence into a small meter, by which its amount is registered. From the amount of water and carbon dioxid thus obtained the amounts of both in the total air breathed are calculated. The water and carbon dioxid previously present in the air are simultaneously determined by a corresponding absorption apparatus and deducted from the amounts obtained from the respired air. As the apparatus is traversed constantly by a column of air of normal composition and the waste products removed as rapidly as discharged, the experiment can be continued for periods varying from six to twenty-four hours without detriment to the subject of the experiment.

With those forms adapted only for animals—Regnault's and Reiset's, or Jolyet and Regnard's—it is possible to determine simultaneously the absorption of oxygen and the discharge of carbon dioxid. As the apparatus employed is completely closed, the carbon dioxid must be removed as soon as discharged and the oxygen re-

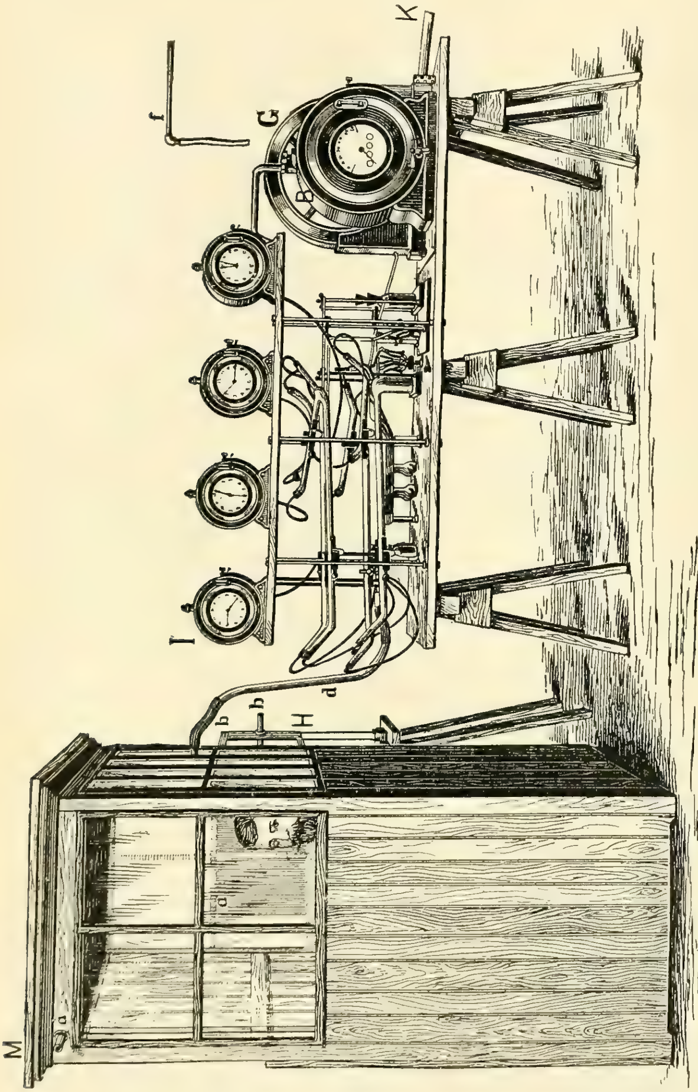


Fig. 199.—The Pettenkofer-Voit Respiration Apparatus. M and H. Chambers for man and animal respectively, in connection, by means of a tube, b, d, with a large gas-meter, B, by which the air is withdrawn from the chamber. A portion of the air is diverted from the tube by small pumps and these forced into and through the absorption tubes. The volume is measured by small gas-meters above. The revolution of the meter is caused by the turning of a water-wheel, G, set in action by water falling from the tube f.

newed as soon as absorbed. The former is accomplished by the aspiratory action of moving bulbs containing an alkali, the latter by a steadily acting pressure on a reservoir of oxygen. This apparatus (Fig. 200) consists essentially of a bell-jar in which the animal is placed. This is brought into connection by tubes, on the one hand, with the oxygen reservoir, and, on the other hand, with the aspiratory bulbs, kept in motion by some form of motor. The construction of each of these forms of apparatus is so complex, the conduct of an experiment and the final determination of the results so complicated, that a detailed description would be out of place in a work of this character.*

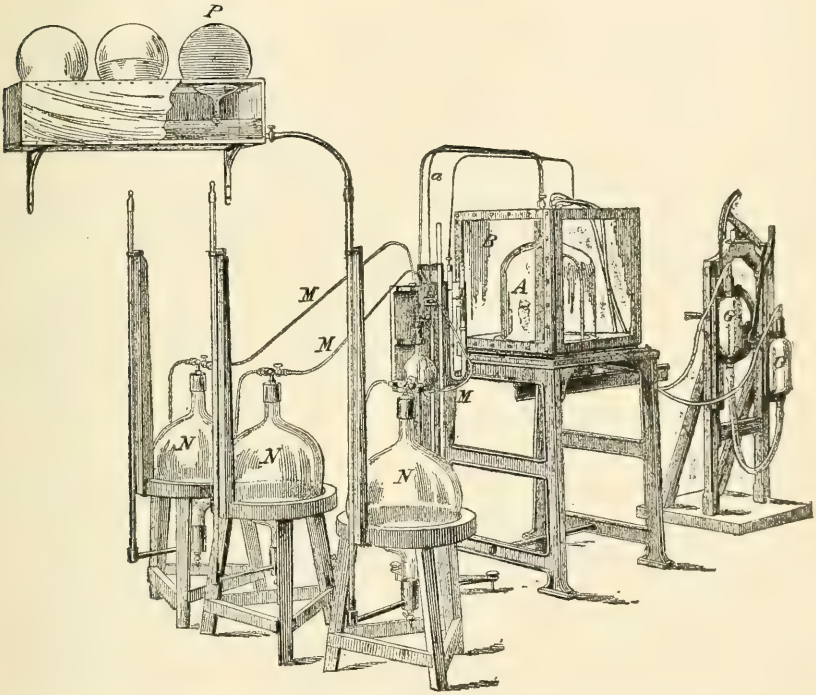


FIG. 200.—REGNAULT'S AND REISET'S RESPIRATION APPARATUS. A. Bell-jar for the reception of the animal, surrounded by a compartment, B, containing water. N, N, N. Reservoirs of oxygen communicating, on the one hand, with the animal chamber, and, on the other hand, with pressure bottles, P, by which the oxygen is driven into the animal chamber. G, G. Aspiratory bulbs containing sodium hydroxid in solution for the absorption of the carbon dioxid. The bulbs are given an alternate up-and-down movement by a falling weight or electric motor.

Among the results obtained by these and other methods a few are given in the following table:

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* Both forms of apparatus are in use in the Physiological Laboratory of the Jefferson Medical College and are fully described by Prof. H. C. Chapman in his text-book on Physiology, to which the reader is directed for further information.

Oxygen Absorbed.	Observer.	Carbon Dioxid Discharged.
746 grams.	Vierordt.	876 grams.
700 “	Pettenkofer and Voit.	800 “
663 “	Speck.	770 “

The amounts of oxygen absorbed in Pettenkofer and Voit's experiments varied from 594 to 1072 grams; of carbon dioxid exhaled, from 686 to 1285 grams.

In all these results it is evident on examination that the volume of oxygen absorbed is always greater than the volume of carbon dioxid exhaled, or, what amounts to the same thing, the weight of the oxygen absorbed is always greater than the weight of the oxygen entering into the formation of the carbon dioxid exhaled. The reason for this difference between the amounts of oxygen in the inspired air and in the CO_2 exhaled is found in the fact that on a mixed diet—one containing fat—a portion of the oxygen is utilized in the oxidation of the hydrogen of the fat with the formation of water. Under such a diet the respiratory quotient is always less than unity, usually 0.907. On a purely carbohydrate diet—one in which there is no surplus hydrogen—all the oxygen will combine with carbon and be returned as carbon dioxid, and hence the respiratory quotient will be unity. The respiratory quotient therefore indicates the extent to which the oxygen absorbed is utilized in oxidizing carbon, on the one hand, and hydrogen, on the other.

Since the total oxygen absorbed and carbon dioxid discharged will vary considerably with the size of the animal, it is customary, for purposes of comparison, to reduce all total results to the unit of body-weight (one kilogram) and to the unit of time (one hour).

Respiratory Activity.—The activity or the intensity of the respiratory process may be measured either by the oxygen absorbed or the carbon dioxid discharged. But as the carbon dioxid is more easily estimated than the oxygen, it is usually taken as the index of the activity, though there are reasons for believing that it would be more accurately indicated or represented by the oxygen.

Whatever factor may be accepted as the measure, it is certain that the respiratory activity varies in different tissues in accordance with their functional activities, being least in bones and greatest in muscles. This is shown by the relative amounts of oxygen absorbed and carbon dioxid discharged by equal amounts of each of these and other tissues in twenty-four hours, as shown in the following table:

QUANTITY OF O AND CO_2 ABSORBED AND EXHALED DURING TWENTY-FOUR HOURS, IN CUBIC CENTIMETERS.

By 100 Grams of:	Oxygen Absorbed.	Carbonic Acid Exhaled.
Muscle,	50.8 c.c.	56.8 c.c.
Brain,	45.8 “	42.8 “
Kidneys,	37.0 “	15.6 “
Spleen,	27.3 “	15.4 “
Testicles,	18.3 “	27.5 “
Pounded bones	17.2 “	8.1 “

The total respiratory change therefore of the body as a whole is the resultant of the respiratory changes of its individual organs and tissues, and is conditioned by all influences which retard or hasten their activity. Among these influences the more important are the following:

Muscle Activity.—As the muscles constitute a large part of the body, about 40 per cent., and as muscle-tissue absorbs and discharges relatively large quantities of oxygen and carbon dioxid, it is readily apparent that an increase in their activity would be followed or attended by an increase in the respiratory exchange. In passing from a condition of body repose to one of marked activity there ought to be an increase in the amount of oxygen absorbed and CO_2 discharged. Pettenkofer and Voit found that a man in repose who absorbed daily 807.8 grams of oxygen and discharged 930 grams CO_2 absorbed during work 1006 grams of oxygen and discharged 1137 grams of CO_2. Edward Smith, who estimated only the CO_2, found that a man in repose who discharged carbon dioxid at the rate of 161.6 c.c. per minute increased the amount while walking at the rate of two and three miles an hour to 569 c.c. and 851 c.c. respectively. Similar results have been obtained by other investigators.

Digestive Activity.—The activity of the alimentary canal, involving contraction of its muscle coat through its entire length as well as secretion of its related glands called forth by the ingestion of food, materially influences the absorption of oxygen and discharge of carbon dioxid, independent of the increase due to the oxidation of food materials after absorption. It was found that in a fasting man a dose of sodium sulphate increased the absorption of oxygen as much as 17 per cent. and the discharge of CO_2 24 per cent. (Löwy). It is difficult to determine how much of the increase after a meal is therefore due to food oxidation and how much to functional activity of the canal itself. The consumption of nitrogenized meals, however, has a greater effect than non-nitrogenized meals.

Temperature.—A rise in temperature of the surrounding air has as an effect a diminution in the amounts of oxygen consumed and carbon dioxid discharged. A fall in temperature has the opposite effect. Thus a cat at a temperature of —3.2° C. consumed during a period of six hours 21.39 grams of oxygen and discharged 22 grams of carbon dioxid, while at a temperature of 29.6° C. the corresponding amounts for the same period of time were for oxygen 13.9 grams and for carbon dioxid 13.12 grams. Lavoisier and Sequin, having reference only to the oxygen, found that a man at a temperature of 15° C. consumed 38.31 grams of oxygen, while at a temperature of 32.8° C. the corresponding amount was but 35 grams. Similar results have been obtained by other observers with different animals. The explanation of these facts is to be found in the increased activity of all physiologic mechanisms coincident with a fall, and in the decreased activity, coincident with a rise in temperature. The lower temperatures act as a stimulus to the peripheral terminations of the nerve system, bringing about reflexly increased activity of the body at large. The muscles especially are not only reflexly but volitionally excited to greater activity. This leads naturally to an increase in the consumption of oxygen and in the production of carbon dioxid and in the evolution of heat.

In cold-blooded animals the respiratory exchange is influenced in a manner the reverse of that observed in warm-blooded animals. With a rise of external temperature and a corresponding rise of body-temperature the discharge of carbon dioxid steadily increases. Thus a frog in an atmosphere at 0° C. with a body-temperature of 1° C. discharged per kilogram per hour 4.31 c.c. of carbon dioxid; in an atmosphere of 35° C. with a body-temperature of 34° C. there was discharged 325 c.c. per kilo per hour. Intermediate temperatures were attended by corresponding increases in the amounts of CO_2 discharged. The reason for this difference in the two classes of animals is probably to be found in the want, in the cold-blooded animals, of a self-adjusting heat-regulating mechanism.

Age.—In early youth, as a result partly of the more pronounced activity of the nutritive energies and partly of a cutaneous surface relatively greater, as compared with the mass of the body, than in adult life, the absorption of oxygen and the discharge of carbon dioxid are greater both absolutely and relatively. Thus, in a boy of nine and a half years with a weight of 22 kilograms it was found that in twenty-four hours there was a discharge of carbon dioxid amounting to 488 grams, or 0.92 gram per kilo per hour, and in man with a weight of 65.5 kilograms there was a discharge of 804.72 grams, or 0.51 gram per kilo per hour.

MODIFICATIONS OF THE RESPIRATORY RHYTHM.

The character of the respiratory movements is materially modified by a change in the quantitative and qualitative composition of the air and blood as well as by changes of a pathologic nature of the respiratory apparatus itself.

Eupnea.—So long as the air retains its normal composition and the respiratory mechanism its structural integrity, so long do the respiratory movements exhibit a normal rhythm and frequency. To the condition of easy tranquil breathing the term *eupnea* is given. In this condition the percentages of oxygen and carbon dioxid in the blood are such as to favor at least the rhythmic discharge of nerve impulses to the respiratory muscles, of sufficient energy and frequency for the maintenance of normal respiration.

Hyperpnea.—The normal rate of the respiratory movements is increased by a rise in body-temperature, by active exercise, and by emotional states. Whatever the cause, the increase in rate and probably in depth is termed *hyperpnea.*

Febrile states characterized by a rise in the temperature of the blood increase considerably the respiratory activity. This is due in all probability to a warming of the respiratory center, in consequence of which its excitability is heightened; for surrounding the carotid arteries with warm tubes and heating the blood on its way to the medulla has the same effect. It is also possible, however, that the high temperature of febrile conditions may interfere with the absorbing power of hemoglobin, and thus by diminishing the quantity of oxygen absorbed lead to more frequent respirations. To the hyperpnea induced by heat the term *thermo-polypnea* is frequently given.

Muscle activity, especially if it is violent and indulged in by those unaccustomed to exercise, is generally followed by increased rate and depth of breathing, and not infrequently it is attended with such extreme difficulty that the condition approximates that of dyspnea. This condition is attributed to the production and discharge into the blood of unknown waste products which act as irritants to the respiratory center and thus increase its activity. As they apparently can not be isolated and their chemic nature determined, it is presumable that they are speedily oxidized or reduced in the blood. Experiment has shown that the increase of carbon dioxid does not account for the increased rate of breathing. Emotional states temporarily increase respiratory activity. With their disappearance the normal condition returns.

Apnea.—If the respiratory movements are voluntarily increased in frequency and depth for a short time it will be found on cessation that for a variable length of time the respiratory mechanism remains in a condition of complete rest or inaction. To this complete cessation of activity the term *apnea* is given. The same phenomenon is witnessed in animals when the lungs are rapidly inflated with air by means of bellows. At one time this was attributed to an excess of oxygen in the blood (the result of the forced ventilation of the lungs), complete saturation of the plasma and hemoglobin, in consequence of which the respiratory center remained inactive. This has been disproved, however, by modern chemic analyses of the blood. The condition is now attributed:

1. To increased ventilation of the lungs and an increased percentage of oxygen in the alveoli, as a result of which the normal percentage of oxygen in the blood can be maintained for a longer period than usual.
2. To a stimulation of the peripheral terminations of the pneumogastric nerve whereby the discharge of nerve impulses from the respiratory center is temporarily inhibited. Division of the pneumogastric nerve prevents the development of the apneic condition.

Dyspnea.—Excessive and laborious respiratory movements constitute a condition known as *dyspnea.* Movements of this character indicate that the blood is deficient in oxygen or overcharged with carbon dioxid. In either case the excitability of the respiratory center is abnormally heightened. These conditions of the blood may be caused: (1) By all those pathologic conditions of the respiratory apparatus which limit the free entrance of oxygen into and the free exit of carbon dioxid from the blood; (2) by those alterations in the composition of the air and subsequently in the blood which arise when the individual is confined in a space of moderate size with imperfect ventilation. The want of oxygen in the blood gives rise to more forcible inspirations; the presence of CO_2 in excess, to more forcible expirations—showing that the former condition affects the inspiratory portion of the respiratory center, the latter condition the expiratory portion. A deficiency in the amount or quality of the hemoglobin is usually attended with dyspnea.

Asphyxia.—If the state of the blood observed in dyspnea be exaggerated—that is, if the decrease in the percentage of oxygen and the increase in the percentage of carbon dioxid become more marked—the respiratory movements become more laborious. A continuance of this changed composition of the blood eventuates in death. Before this occurs the individual exhibits a succession of phenomena, to the totality of which the term *asphyxia* is given.

Asphyxia may be caused: (1) By a sudden interference with the entrance of oxygen into and the exit of carbon dioxid from the blood, as in drowning, occlusion of the trachea from any cause, double pneumothorax, etc. (2) By confinement in a small space the air of which speedily undergoes a loss of oxygen and an accumulation of carbon dioxid. In the first instance death may occur in a few minutes; in the second instance it may be postponed several hours or more, the time varying with the size of the space.

The succession of phenomena presented by an individual in the asphyxiated condition is as follows: Increased rate and depth of the respiratory movements, passing rapidly from hyperpnea to dyspnea, with an active contraction of all the muscles concerned in respiration, ordinary and extraordinary; a blue cyanosed condition of the face from the rapid accumulation of carbon dioxid and disappearance of the oxygen of the blood; a diminution in the depth of inspiration and an increase in the force and extent of expiration, followed by general convulsions; collapse, characterized by unconsciousness, loss of the reflexes, relaxation of the muscles, a weak action of the heart, a disappearance of the pulse and death. As shown by observation of the circulatory apparatus in artificially induced asphyxia, there is primarily an increase in the activity of the heart, soon followed by retardation; a rise of blood-pressure in the early stages and a fall to zero after collapse has set in. The retardation and final cessation of the heart, as well as the rise of the blood-pressure, are to be attributed to stimulation of the cardio-inhibitory and vaso-motor centers from the accumulation of the carbon dioxid. With the exhaustion of the nerve-centers, there is a general relaxation of the muscles and a fall of the pressure.

The Cheyne-Stokes Respiration.—A modification of the respiratory movements characterized by periods of rest alternating with periods of activity was described in 1818 and in 1854 by the two writers whose name it bears. The periods of rest vary in duration from twenty to thirty seconds; the periods of activity from thirty to sixty seconds and may include from twenty to thirty respiratory movements.

Each period of rest of the respiratory mechanism is closed by the appearance of a slight shallow respiratory movement, which is immediately followed by a second, slightly deeper, and this in turn by a third, a fourth, a fifth, and so on, each becoming deeper than the preceding until a certain maximum is reached, after which, each succeeding movement gradually diminishes in depth until finally the movement becomes imperceptible and a new period of rest supervenes. A graphic representation of the Cheyne-Stokes type of respiration is shown in Fig. 201. This type of respiration is frequently an accompaniment of certain pathologic conditions, *e. g.*, uremic states, cerebral hemorrhage, heart diseases, arteriosclerosis, etc., though no satisfactory explanation of it has yet been presented. A similar though far less marked periodicity in the respiratory movements is frequently observed during normal sleep, especially in children. A periodicity can also be developed by dividing transversely the medulla oblongata just above the calamus scriptorius which either injures the respiratory center or removes from it some cerebral influence.

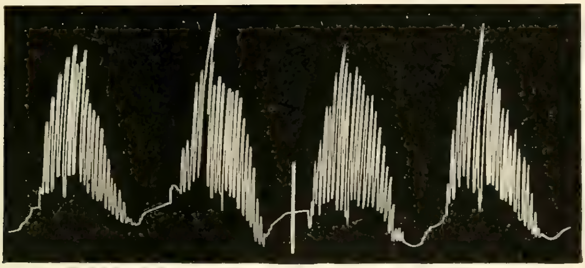


FIG. 201.—TRACING SHOWING THE CHEYNE-STOKES FORM OF RESPIRATION.—(*Hill.*)

THE NERVE MECHANISM OF RESPIRATION.

The nerve mechanism by which the respiratory muscles are excited to action is extremely complex and involves the action of both afferent and efferent nerves and their related nerve-centers in the central nerve system. For the free introduction of air into the lungs it is essential that the nasal and laryngeal passages and the cavity of the thorax be simultaneously enlarged. The muscles by which these results are accomplished have already been mentioned and described. Their simultaneous and coördinate contraction implies the coördinate activity of motor nerves and their centers; thus, the nasal and laryngeal muscles (the dilatator naris and the posterior crico-arytenoid) involve the activity of the facial and inferior laryngeal nerves respectively, the centers of origin of which lie in the gray matter beneath the floor of the fourth ventricle; the diaphragm and intercostal muscles involve respectively the activity of the phrenic and intercostal nerves, the centers of origin of which lie in the anterior horn of the gray matter of the spinal cord at a level, for the phrenic, of the fourth, fifth, and sixth cervical nerves, and for the intercostals at the level of the upper thoracic nerves. Division of any one of these nerves is followed by paralysis of its related muscle.

Inspiratory Center.—The coördinate contraction of the inspiratory muscles implies a practically simultaneous discharge of nerve impulses from each of the foregoing nerve-centers, accurately graduated in intensity in accordance with inspiratory needs. This has been supposed to necessitate the existence in the central nerve system of a single group of nerve-cells from which nerve impulses are rhythmically discharged and conducted to the previously mentioned nerve-centers in the medulla oblongata and spinal cord, by which they are in turn excited to activity. To this group of cells the term "inspiratory center" has been given.

For the free exit of air from the lungs it is not only essential that the air-passages be open, but that the air in the lungs be compressed until its pressure rises above that of the atmosphere. This is accomplished by the recoil of the elastic tissue of the lungs and thorax, the return of the displaced abdominal organs aided by atmospheric pressure, and the contraction of the expiratory muscles. In how far muscle action is necessary for expiratory purposes will depend on the resistance offered to the outflow of air and on the degree of efficiency of the elastic forces.

Expiratory Center.—The simultaneous and coördinate activity of the expiratory muscles in impeded expirations also involves the action of motor nerves and nerve-centers. The simultaneous and coördinate discharge of nerve impulses, also graduated in intensity for expiratory needs, apparently implies the existence in the central nerve system of a single center from which nerve impulses are rhythmically discharged which excite and coördinate the lower nerve-centers. To this group of cells the term "expiratory center" has been given. The two centers taken together constitute the so-called "respiratory center."

The anatomic existence, however, of a definite group of cells which initiates the respiratory movements has not as yet been demonstrated. Nevertheless there is in the dorsal portion of the medulla oblongata, at the level of the sensory end-nucleus of the vagus nerve, a region the sudden destruction of which on one side is followed by a cessation of respiratory movements on the corresponding side, though they continue on the opposite side, a fact which indicates that the area, though acting as a unit, is bilateral. The bilateral character of the area is also shown by the continuance of the respiratory movements on both sides after longitudinal division of the medulla. Destruction of the entire region is followed by a complete cessation of respiratory activity and death of the animal. For this reason the term "nœud vital" was applied to it. In this area the respiratory center was located. It has, however, been shown by Gad that if this area be gradually destroyed by cauterization the respiratory movements do not cease, but continue until the cauterization has reached a point far forward in the formatio reticularis, in which the respiratory center was assumed to lie.

Though its existence has not been anatomically determined beyond question, it is permissible to speak of the central mechanism as a "center" located in the medulla oblongata.

The activity of the inspiratory center has long been described as automatic or autochthonic (Gad) in character, expressive of the idea that the rhythmic discharge of nerve impulses is conditioned by the composition of the blood or lymph by which it is surrounded, though susceptible to the action of nerve impulses reflected to it through afferent nerves. Thus so long as the blood retains its normal composition the inspiratory movements are normal. If, however, the blood becomes richer in oxygen and relatively poorer in carbon dioxid, the rate of discharge of nerve impulses and hence the inspiratory movements, diminish until the condition of apnea results. If, on the contrary, the blood becomes poorer in oxygen and richer in carbon dioxid, the reverse condition obtains: viz., an increased rate of discharge of nerve impulses, increased frequency of inspiration, hyperpnea, and dyspnea. This view of the automaticity of the inspiratory center is supported by the fact that the center continues more or less active after division of the medulla oblongata just posterior to the corpora quadrigemina, of the spinal cord at the level of the seventh cervical nerve, of the vagus nerves and the posterior roots of the cervical nerves, channels through which the majority of nerve impulses reach the center. Whether the center would continue active after division of all remaining afferent nerves, *e. g.*, trigeminal and glossopharyngeal, it is impossible to state, since from the nature of the case such an experiment would be most difficult to perform.

The first inspiration after birth is supposed to be due to the direct stimulation of the respiratory center by the increase in the carbon dioxid present in the blood, though it may be aided by the cooling of the skin due to vaporization of the amniotic fluid.

Reflex Stimulation of the Inspiratory Center.—Whether the inspiratory center is automatic in character or not, it may be influenced directly by nerve impulses descending from the brain in consequence of volitional acts or emotional states, and indirectly by nerve impulses reflected to it from the general periphery through various afferent nerves, in consequence of agencies acting on their peripheral termination: *e. g.*, cold applied to the skin, irritating gases to the nasal and bronchial mucous membrane, distention and collapse of the pulmonary alveoli.

Of all afferent nerves, the vagus appears to be the most influential in maintaining the rhythmic discharge of nerve impulses from the inspiratory center. (Fig. 202). Thus, if while the animal is breathing regularly and quietly both vagi are cut, the respiratory movements become much slower, falling perhaps to one-third their original number per minute. If the central end of the divided vagus be stimulated with weak faradic currents, the respiratory movements are increased in frequency and their depth diminished until the normal rate is restored. With the cessation of the stimulation the former condition at once returns. This would indicate that in the physiologic state afferent impulses are ascending the vagus fibers which influence the rate of discharge from the inspiratory center. If, however, the stimulation is increased in strength, the inspiratory movement gradually so exceeds the expiratory that the muscles pass into the tetanic state and the chest-walls come to rest in the condition of forced inspiration. The vagus apparently contains fibers which augment the inspiratory movement. If, on the other hand, the central end of the divided superior laryngeal nerve be stimulated with faradic currents, the opposite effect is produced: viz., an excess of the expiratory over the inspiratory movement until the chest-walls come to rest in the condition of passive expiration. The superior laryngeal nerve apparently contains fibers which inhibit the inspiratory movement.

The same result, an expiratory standstill, not infrequently follows strong stimulation of the divided vagus, and always after the administration of large doses of chloral.

The vagus apparently contains two classes of nerve-fibers, one of which when stimulated increases the extent of the inspiratory movement until the thorax comes to a standstill in the state of forced inspiration; the other of which when stimulated increases the extent of the expiratory movement at the expense of the inspiratory until the thorax comes to a standstill in a state of deep expiration.

The stimulus adequate to the excitation of the nerve-fibers in the physiologic condition was formerly believed to be the chemic action of carbon dioxid; it is now believed to be a mechanic action, the result of the alternate distention and collapse of the walls of the pulmonary alveoli. Thus, it has been shown by Head that if the lungs are actively inflated (positive ventilation) there will be produced an inhibition of the inspiratory and an augmentation of the expiratory movement until the inspiratory muscles are completely relaxed as indicated by the relaxation of the diaphragm, the movements of which are simultaneously recorded (Fig. 203), a result similar in all respects to that produced by stimulation of the superior laryngeal nerve. On the other hand, if the lungs are collapsed by the artificial withdrawal of air (negative ventilation) there will be produced an augmentation of the inspiratory and an inhibition of the expiratory movements until the inspiratory muscles are in a condition of tetanic contraction as indicated by the contraction of the diaphragm (Fig. 204) and by the state of the thorax which is that characteristic of extreme inspiration,

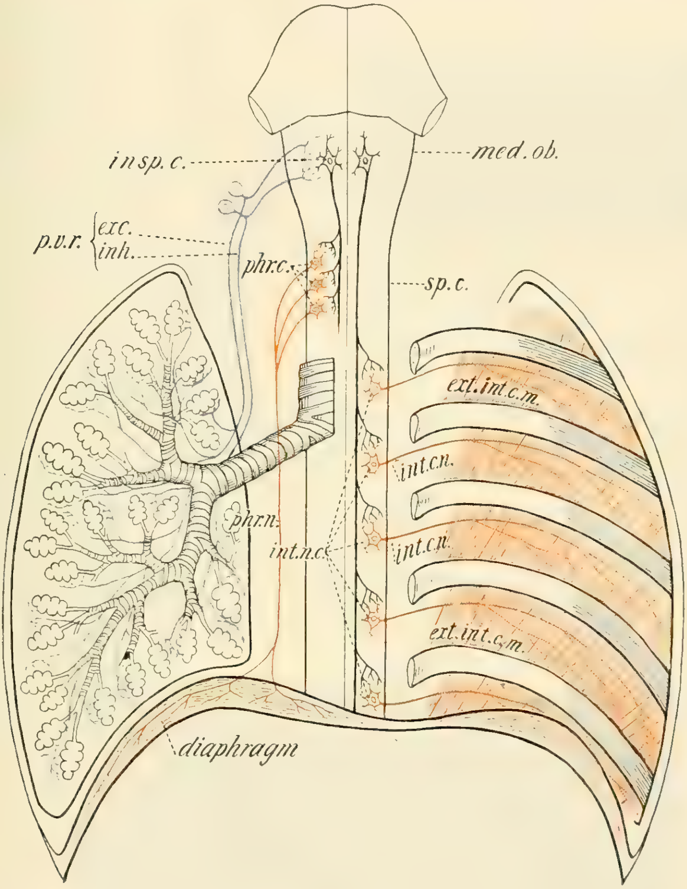


FIG. 202.—DIAGRAM SHOWING THE RELATION OF THE PULMONARY FIBERS OF THE VAGUS TO THE INSPIRATORY CENTER AND THE CONNECTIONS OF THE LATTER WITH THE PHRENIC AND INTERCOSTAL NERVE CENTERS AND THEIR RELATED MUSCLES. (*G. Bachman.*) *med. ob.* Medulla oblongata. *sp. c.* Spinal cord. *p.v.r.* Pulmonary vagus nerve, excitator and inhibitor. *insp. c.* Inspiratory center. *phr. c.* Phrenic nerve centers. *phr. n.* Phrenic nerve *int. n. c.* Intercostal nerve centers. *int. c. n.* Intercostal nerves. *ext. int. c. m.* External intercostal muscles.

a result similar in all respects to that produced by moderate stimulation of the central end of the divided vagus.

A satisfactory explanation of the action of the respiratory mechanism is very difficult to present. Theories vary in accordance with the estimate of an investigator as to the degree of automaticity of the inspiratory center, of the effects of vagus stimulation and as to the extent to which the expiratory center is involved with the activity of the inspiratory center either simultaneously or successively.

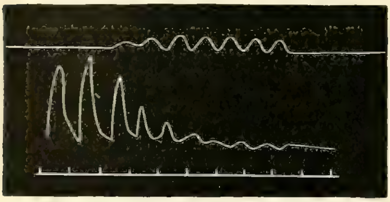


Fig. 203.—Positive Ventilation (*Head*). Under the influence of positive ventilation, the inspiratory contractions of the diaphragm become less and less till they disappear completely.

If it is assumed that the inspiratory center is automatic and in a state of continuous excitation the result of the action of carbon dioxid in the blood circulating around it, then it is only necessary to assume the existence, in the trunk of the vagus of but one set of nerve-fibers, viz., inhibitor fibers, the central terminations of which arborize around the inspiratory center and the function of which is to check or inhibit the action of the inspiratory center and thus permit of an expiratory movement. The inhibitor fibers are supposed to be stimulated peripherally by the expansion of the lungs. With the recoil of the lungs the inhibitor effect gradually dies away, while the inherent excitation of the inspiratory center again returns, to be followed by another discharge of nerve impulses and a new inspiratory movement, which will in turn be again inhibited as the inhibitor fibers are stimulated by the expanding lung. This explanation is in accordance with the results

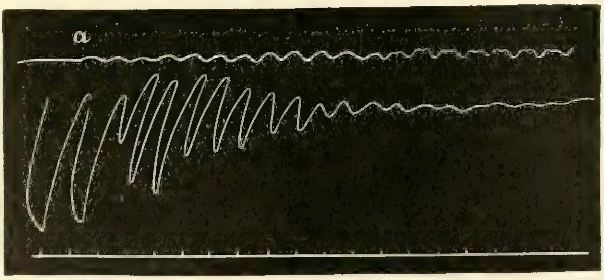


Fig. 204.—Negative Ventilation (*Head*). At *a* negative ventilation was commenced. The expiratory relaxation of the diaphragm is seen to become more and more incomplete, until it finally enters into continued contraction.

which follow stimulation of the superior laryngeal nerve or the trunk of the vagus with strong induced electric currents.

If it is assumed, on the contrary, that the inspiratory center is not in a state of constant excitation leading to a continuous discharge of nerve impulses, but requires the arrival of a stimulus to call forth its normal activity, then this theory does not suffice, inasmuch as it leaves out of consideration the presence of nerve-fibers in the vagus which increase or augment the activity of the inspiratory center; and that such fibers are present is apparently indicated by the effects of stimulation of the central end of the vagus nerve with weak and moderately strong induced electric currents and from the experiments of Hering and Breuer, and later of Head. These observers assume, therefore, that in addition to the inhibitor fibers there are also present in the vagus, excitator fibers, the central terminations of which are in relation with the inspiratory center also (Fig. 202); and just as the inhibitor fibers are stimulated by the expansion of the lungs so the excitator fibers are stimulated in turn by the recoil of the lungs. The nerve impulses thus developed ascend to the inspiratory center, excite it, and call forth a new inspiration sooner than it would otherwise take place. According to this view the respiratory mechanism is self-regulative and maintained by the alternate expansion and recoil of the lungs.

Many experimenters, however, find difficulty in accepting the view that the recoil of the lungs should stimulate nerve endings and hence this theory has not received general acceptance.

Another explanation which is satisfactory in many respects has been presented by Meltzer. This investigator asserts also the existence in the trunk of the vagus the two classes of nerve-fibers, the inhibitor and the excitator; but that for some reason they do not respond to stimulation at the same time as shown by the effects which follow; the inhibitor fibers respond first and the excitator fibers somewhat later. Therefore when they are stimulated simultaneously the primary effect is an inhibition of the inspiratory center followed by an expiratory movement. The secondary effect is a stimulation of the inspiratory center followed by a new inspiratory movement. In this view expansion of the lungs stimulates both the inhibitor and the excitator fibers, but during the expansion and for a short time after, the effect of the inhibitor stimulation, viz., cessation of inspiration and the advent of expiration, alone manifests itself. With the cessation of expiration, the inhibitor stimulation dies away and the late effect or the long after-effect of the excitator stimulation, viz., a new inspiration, manifests itself. This author assumes the surface of the lung to be the peripheral organ of the respiratory reflexes.

When it is assumed that both inspiratory and expiratory centers coöperate in a respiratory movement, as they do in labored respiration either simultaneously or successively, the difficulties of the problem are manifestly much greater. In this case it may be supposed that afferent impulses, developed during the expansion of the lung, inhibit the inspiratory while augmenting the expiratory center, and that impulses developed during the recoil of the lungs inhibit the expiratory while stimulating the inspiratory center.

THE EFFECT OF THE RESPIRATORY MOVEMENTS ON THE FLOW OF BLOOD THROUGH THE INTRA-THORACIC VESSELS AND ON THE ARTERIAL PRESSURE.

1. **On the Intra-thoracic Vessels.**—The forces which cause the air to flow into and out of the lungs will at the same time and in the same way cause the blood of the systemic vessels to flow into, through, and out of the intra-thoracic vessels. From the tendency of the pulmonary elastic tissue to recoil, the blood-vessels in the thorax at the end of an expiration sustain a positive pressure, about six millimeters of mercury less, than that in the lungs, or, in other words, a pressure negative to that of the atmosphere by six millimeters. As a result the blood in the systemic vessels standing under atmospheric pressure will flow steadily toward the intra-thoracic veins, the venæ cavæ, and the right side of the heart; *i. e.*, from a point of high to a point of low pressure. Since during inspiration, with the increasing tendency to pulmonary recoil, the positive pressure on the veins and heart may diminish by thirty millimeters of mercury, the blood will flow in increased volume from the systemic to the intra-thoracic vessels. The right heart, being more generally filled with blood, will discharge a larger volume with each contraction into the pulmonary artery.

Coincident with these effects a similar effect is produced in the arterioles and capillaries of the pulmonary alveoli. Situated between the two elastic layers of the alveolar wall, embedded in a meshwork of connective tissue, the pressure to which they are subjected at the end of an expiration will also be a few millimeters less than that of the intra-pulmonary air; and at the end of an inspiration it will be considerably less. With the inspiration there will occur a dilatation of the vessels, a larger flow of blood through them and into the pulmonary veins. The left heart, being in consequence more generously filled with blood, will discharge a larger volume into the aorta at each contraction. During expiration the flow of blood through the intra-thoracic vessels will be diminished for the reverse reasons.

2. **On the Arterial Pressure.**—An examination of a tracing of the arterial pressure will show that it is characterized by small undulations due to the cardiac beat and large undulations due to the respiratory movements, inspiration being accompanied by a rise, expiration by a fall of pressure. These results are readily accounted for by the difference in the volume of blood discharged by the left heart into the aorta during the time of the two movements. If a tracing of the respiratory movements and of the blood-pressure be taken simultaneously, it will be found that the rise of pressure does not exactly correspond with inspiration, nor the fall of pressure with

expiration; for a certain period after the beginning of an inspiration the pressure continues to fall, and for a certain period after the beginning of an expiration the pressure continues to rise. During the remainder of the period, however, inspiration is attended by a rise, expiration by a fall of pressure. The explanation of these results lies in the fact that at the beginning of the inspiration, when the vessels dilate, the blood-flow momentarily slows; the left heart continuing to discharge small volumes into the aorta, the pressure continues to fall. So soon as the left heart begins to be better filled, the pressure at once begins to rise. At the end of an expiration the flow of blood into the left heart continues and the pressure rises, but with the return of the intra-thoracic pressure the vessels diminish in caliber, the volume of blood transmitted by them becomes less, the output of the left heart declines, and the pressure falls.

The Traube-Hering Waves.—Under certain experimental conditions the arterial blood-pressure tracing exhibits, in addition to the usual respiratory variations, certain longer rhythmic variations more or less wave-like in character, which are known as Traube-Hering waves. They can be developed on a blood-pressure tracing by injecting magnesium sulphate or morphine into the circulation, by tying the cerebral arteries, etc. These waves indicate a periodic contraction and dilatation of the blood-vessels the result of a stimulation of the vaso-motor centers.

CHAPTER XVI.

ANIMAL HEAT.

The chemic changes which take place in the tissues and organs of the living body and which underlie all manifestations of life are attended by the evolution of heat. In consequence of this each animal acquires a certain body-temperature.

In man, as well as in other mammals and in birds, the chemic changes are extremely active and the evolution of heat very great. Through some special heat-regulating mechanism, by which heat-production and heat-dissipation are kept in equilibrium, these animals have acquired and maintain within limits a constant temperature which is independent of and generally above that of the surrounding atmosphere. As the temperature of these animals is high and perceptible to the sense of touch, they were originally designated "warm-blooded" animals. As this temperature is constant notwithstanding the great variations in external temperature during the summer and winter seasons, they are more appropriately termed constant-temperatured or *homoiothermous* animals. The intensity of the body-temperature determined by the insertion of a thermometer in the rectum varies in different classes of mammals from 37.2° C. to 40° C. The causes of this variation are doubtless connected with peculiarities of organization. In birds the rectal temperature is usually higher, varying from 40.9° C. in the pigeon to 44° C. in the titmouse and the swift.

In reptiles, amphibians, and fish chemic changes, as a rule, are not very active and heat-production relatively slight. As they are devoid of a sufficiently active heat-regulating mechanism, the temperature of the body is largely dependent on that of the medium in which they live, though it is always one or more degrees above it. In winter the body-temperature of frogs, for example, may decline as low as 8.9° C., the temperature of the surrounding medium being 6.7° C. When subjected to temperatures below zero, the temperature of the body may fall below the freezing-point also, when the lymph and fluids of the body become ice. Though apparently dead, the gradual elevation of the temperature restores their vitality. In summer-time, on the contrary, the body-temperature may attain to 38° C. Similar variations have been observed in other animals. As the temperature of these animals is low and perceptibly below that of our own bodies, they were originally termed "cold-blooded" animals; as their temperature is inconstant, varying with the temperature of the surrounding medium, they are more appropriately termed "variable temperatured" or *poikilo-thermous* animals.

THE TEMPERATURE OF THE HUMAN BODY.

The determination of the temperature of the human body under the changing conditions of life is a matter of the greatest physiologic and clinical interest. The temperature of the superficial portions of the body may be obtained by the introduction of a thermometer into the mouth, the rectum, the vagina, or the axilla. As a result of many observations it has been found that the temperature of the rectum is, on the average, 37.2° C.; that of the mouth, 36.8° C.; that of the axilla, 36.9° C. Owing to radiation and conduction the surface temperature is lower than that of either the mouth or rectum, and varies to a slight extent in different regions of the body: *e. g.*, at a room-temperature of 20° C. the skin of the pectoral region has a temperature of 34.7°; that of the cheek, 34.4°; that of the calf, 33.6°; that of the tip of the ear, only 28.8°, etc.

In the interior of the body, especially in organs in which oxidation takes place rapidly, and which at the same time are protected by their anatomic surroundings from rapid radiation, the temperature is higher than that observed in the rectum. From an investigation of the temperature of the blood as it emerges from the liver, the muscles, the brain, alimentary canal, etc., it is evident that these organs have a higher temperature than the rectum.

As the chemic changes underlying physiologic activity vary in intensity and extent in different regions of the body, there would be marked variations in their temperature were it not that the blood, having a large capacity for heat-absorption, distributes the heat almost uniformly to all portions of the body, so that at a short distance beneath the surface the temperature does not vary but within a few degrees.

In the dog the temperature of the blood in the aorta and in its principal branches is approximately 38.3° C. In passing through the systemic capillaries the temperature falls from radiation and conduction to surface temperature, to again rise as the venous blood approaches the deeper regions of the body. In the neighborhood of the renal veins and in the superior vena cava the temperature is again that of the aorta. In the portal vein the temperature rises to 40.2° C.; in the hepatic vein, to 40.6° C. In the right ventricle, owing to the admixture of blood from different localities having different temperatures, the temperature falls to 38.2° to 40.4°. In passing through the pulmonary capillaries the temperature of the blood again falls, so that in the left ventricle it will register from 38° C. to 40.2° C. There is thus usually a difference between the two sides of the heart of about 0.2° C.

Variations in the Mean Temperature.—The mean temperature of the human body for twenty-four hours, which for the mouth and the rectum may be accepted at 36.7° C. and 37.2° C. respectively, is subject to variations from a variety of circumstances, such as age, periods of the day, food, exercise, etc.

Age.—At birth the temperature of the infant is slightly higher than that of the mother, registering in the rectum about 37.5° C. In a few hours it rapidly declines to about 36.5°, to be followed in the course of twenty-four hours by a rise to the normal or slightly beyond. During childhood the temperature gradually approximates that of the adult. In old age the temperature rises, as a rule, and attains a maximum at eighty years of 37.4° C.

Periods of the Day.—The observations of Jürgensen show that there is a diurnal variation in the mean temperature of from 0.5° C. to 1.5° C., the maximum occurring late in the afternoon, from 5 to 7 o'clock, the minimum early in the morning, from 4 to 7 o'clock. This diurnal variation in the mean temperature is related to corresponding variations in many other physiologic processes, and its causes are to be found in the ordinary habits of life as regards the time of meals, periods of exercise, sleep, etc.

Food and Drink.—The ingestion of a hearty meal increases the temperature but slightly—not more than 0.5° C. Insufficiency of food lowers the temperature; total withdrawal of food, as in starvation, is followed by a steady though slight decline, until just preceding the death of the animal, when it falls abruptly to from 6° to 8° C. Cold drinks lower, hot drinks raise the temperature. Food and drinks, however, only temporarily change the mean temperature, and after a short period equilibrium is restored through the activity of the heat-regulating mechanism. Alcoholic drinks lower the temperature about 0.5° C. In large toxic doses in persons unaccustomed to their use the temperature may be lowered several degrees. This is attributed not to a diminution in heat-production, but rather to an increase in heat-dissipation (Reichert) from increased action of the heart, dilatation of the blood-vessels of the skin, and increased activity of the sweat-glands.

Exercise.—The temperature may be raised by active muscular exercise from 1° to 1.5° C. as a result of increased activity in chemic changes in the muscles themselves. A rise beyond this point is prevented by the increased activity of the circulatory apparatus, the removal of the heat to the surface, and its rapid radiation.

External Temperature.—The external temperature influences but slightly the mean temperature of the human body. In the tropic as well as in the arctic regions, notwithstanding the change in the temperature of the air, that of the body remains almost constant. The same is true for the seasonal variations in the temperature of the temperate regions.

THE SOURCE AND TOTAL QUANTITY OF HEAT PRODUCED.

The Source of Heat.—The immediate source of the body-heat is to be found in the chemic changes which take place in all the tissues and organs of the body. Each contraction of a muscle, each act of secretion, each exhibition of nerve-force, is accompanied by the evolution of heat. The chemic changes are for the most part of the nature of oxidations, the union of oxygen with the elements, carbon and hydrogen, of the food principles either before or after they have become constituents of the tissues. The ultimate source of the body-heat is the latent or potential energy in the food principles, which was absorbed from the sun's energy and stored up during the growth of the vegetable world. In the metabolism of the animal body the food principles are again reduced through oxidation, directly or indirectly, to relatively simple bodies, such as urea, carbon dioxid, and water, with a liberation of a large portion of their contained energy which manifests itself as heat and mechanic motion.

The Total Quantity.—The total quantity of heat liberated in the body daily may be approximately determined in at least two ways: (1) By determining experimentally the heat values of different food principles by direct oxidation; (2) by collecting and measuring with a suitable apparatus, a calorimeter, the heat evolved by the oxidation of the food within, and dissipated from, the body daily.

1. *Direct Oxidation.*—The amount of heat which any given food principle will yield can be determined by burning a definite amount—*e. g.*, 1 gram—to carbon dioxid and water and ascertaining the extent to which the heat thus liberated will raise the temperature of a given amount of water, *e. g.*, 1 kilogram. The amount of heat may be expressed in gram or kilogram degrees or calories; a gram calorie or kilogram calorie being the amount of heat required to raise the temperature of a gram or a kilogram (1000 grams) of water 1° C. The apparatus employed for this purpose is termed a calorimeter, which consists essentially of a closed chamber, in which the oxidation takes place, surrounded by a water-jacket. The rise in temperature of the water indicates the amount of heat produced.

The results obtained by investigators employing different calorimeters and different food principles of the same class vary, though within narrow limits: *e. g.*, 1 gram casein yields 5.867 kilogram calories; 1 gram of lean beef, 5,656; 1 gram of fat, 9.353, 9.423, 9.686 calories; 1 gram of starch or sugar, 4.116, 4.182, 4.479, etc., calories. These results are, however physical values, and indicate the quantity of heat such quantities of foods give rise to when completely oxidized to carbonic acid and water. In the human body the carbohydrates and the fats, with the exception of the small portion which escapes digestion, are reduced to carbon dioxid and water, and hence practically liberate as much heat as they do when oxidized outside the body. The proteids, however, are only reduced to the stage of urea. As this compound is capable of further reduction in the calorimeter to carbon dioxid and water, with the liberation of heat, the quantity of heat it contains must therefore be deducted from the physical heat value of the proteid. According to Rubner, 1 gram of urea will yield 2.523 kilogram calories. As about one-third of a gram of urea results from the oxidation of 1 gram of proteid, the amount of heat to be deducted from the heat value of the proteid is $\frac{1}{3}$ of 2.523, or 0.841 calories. It has also been shown by the same investigator that some of the ingested proteid is found in the feces, the heat value of which must also be determined and deducted. This having been done, the physiologic heat value becomes 4.124 calories.

The following estimates give approximately the number of kilogram calories which should be liberated within the body when the proteid is burned to the stage of urea, and the fat and carbohydrate to the stage of carbon dioxid and water:

1 gram of proteid	4.124 calories
1 " fat	9.353 "
1 " carbohydrate	4.116 "

The total number of kilogram calories yielded by the various diet scales can be readily determined by multiplying the quantities of the food principles consumed by the foregoing factors. The diet scale of Vierordt, for example, yields the following:

120 grams of proteid	494.88 calories
90 " fat	841.77 "
330 " starch	1358.28
Total,	2694.93 "

The total calories obtained from other diet scales would be as follows: Ranke's, 2335; Voit's, 3387; Moleschott's, 2984; Atwater's, 3331; Hultgren's, 3436. These numbers indicate theoretically the total heat-production in the body daily.

2. *Calorimetric Measurements.*—By this method the heat dissipated from the body of an animal is directly collected and measured, and the amount so obtained is taken as a measure of the heat evolved by the oxidation of the food. A calorimeter is therefore an apparatus for the direct estimation of the quantity of heat dissipated from the body in a given time. The substance employed for collecting and measuring the heat is either water or air. The calorimeters in general use consist essentially of two metallic boxes placed one within the other, though separated by a space sufficiently large to hold a definite amount of water (Fig. 205). The animal is placed in the inner box, which is also provided with tubes for the entrance of fresh and the exit of expired air. The heat radiated is absorbed by the water and its temperature raised. To prevent loss by radiation and to render it independent of changes in the surrounding temperature the calorimeter is surrounded by a poorly conducting material, such as wool. The temperature of the animal is taken at the beginning and the end of the experiment. If the temperature of the animal remains the same at the end of the experiment, then the heat absorbed by the water represents the amount produced by the animal. If, on the contrary, the temperature of the animal rises or falls, the number of calories so re-

tained or lost must be added to or subtracted from the amount absorbed by the calorimeter. In the determination of the absolute amount of heat retained or lost by the animal above or below the initial temperature, as well as that absorbed by the materials of the apparatus in these various instances, the water equivalent of the tissues of the animal and the materials of the calorimeter must be obtained, and then added to or subtracted from, as the case may be, the amount of water in the calorimeter, and the amount thus obtained multiplied by its rise in temperature. In properly conducted experiments in which the sources of error are reduced to a minimum there is a very close correspondence between the total physiologic heat value of the food and the amount collected by the calorimeter. Thus, in an experiment detailed by Rubner, a dog was given during twelve days 228.06 grams of proteid and 340.4 grams of fat the physical heat value of which was estimated at 4419 calories. The urine and feces during this period were collected and their heat value determined, which amounted to 305 calories. The heat which theoretically should have been produced was 4119 calories. During the experiment the calorimeter actually absorbed 3958 calories, a difference between the theoretic and experimental results of 156 calories; thus of the total energy liberated 96 per cent. appeared as heat.

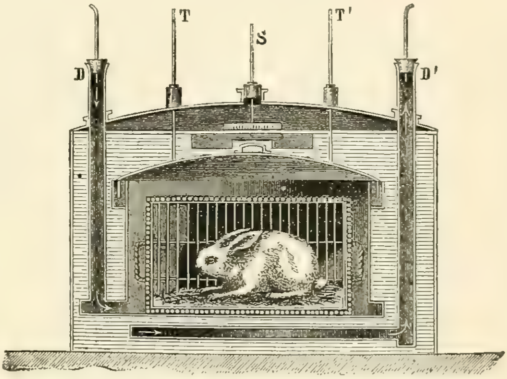


FIG. 205.—WATER CALORIMETER OF DULONG. D and D′. Tubes for the entrance and exit of air. T and T′. Thermometers for ascertaining the temperature of the water. S. A mechanic contrivance for stirring the water for the purpose of distributing the absorbed heat uniformly. To prevent the escape of heat with the expired air, the tube D′ is wound many times in the water-space beneath the animal cage.

Calorimetric experiments on man corresponding to those made by Rubner on dogs have not been successful, owing purely to technical difficulties. Various attempts have been made, however, to determine the daily heat-dissipation. Liebermeister immersed a man in a bath with a temperature lower than that of the man's body. From the rise in temperature of the water it was calculated that the man produced daily 3525 calories. Leyden placed the leg alone of a man in a calorimeter. In one hour 6 calories were absorbed. Assuming that the total superficial area of the body was fifteen times that of the leg, he calculated, taking into consideration various sources of error, that the entire body would produce daily 2376 calories. Ott, employing a water calorimeter, found that the body of a man produced 103 calories during an afternoon, or at the rate of 2472 calories daily. These and similar experiments, while not free from many objections, furnish results which indicate that the heat dissipated from the body approximates the physiologic heat values of the foods.

HEAT-DISSIPATION AND REGULATION OF THE TEMPERATURE.

Heat-dissipation.—From the preceding statements it is evident that the body is continually liberating heat in amounts daily far in excess of that necessary for the maintenance of the body-temperature. Should this heat be retained, the temperature of the body would be raised at the end of twenty-four hours an additional 18° or 20° C.—a temperature far in excess of that compatible with the maintenance of physiologic processes. That the body may be kept at the mean temperature of 37.8° C. it is essential that the heat liberated be dissipated as fast as it is produced, or to state the problem in another way, the heat dissipated by the body must be replaced by an equal amount liberated, if equilibrium of temperature is to be maintained. The dissipation of the heat is accomplished in several ways: (1) In warming the food and drink to the temperature of the body. (2) In warming the inspired air to the same temperature. (3) In the evaporation of water from the lungs. (4) In evaporating water from the skin. (5) In radiation and conduction from the skin. The quantities of heat lost to the body by these different processes it is difficult for obvious reasons to accurately determine, and the estimates usually given must be regarded only as approximative.

Assuming 2500 calories to be an average of heat liberated during a day of repose, the losses, in the ways stated above, may be given as follows:

1. *In Warming Food and Drink.*—The average temperature of food and drink is about 12° C.; the amount of both together is about 3 kilograms; the specific heat of food about 0.8 that of water. The absorption of body-heat therefore by the food amounts approximately to $3 \times 0.8 \times 25°$ C. = 60 calories = 2.8 per cent. With the removal of the end-products of the foods and drink from the body an equal amount of heat is carried out.
2. *In Warming the Inspired Air.*—The average temperature of the air is 12° C.; the amount of inspired air, about 15 kilograms; the specific heat of air, 0.26. The absorption of body-heat by the air until it attains the temperature of the body will therefore amount to $15 \times 0.26 \times 25° = 97.5$ calories = 3.8 per cent. The expired air removes from the body a corresponding amount.
3. *In the Evaporation of Water from the Lungs.*—The quantity of water evaporated from the lungs may be estimated at 400 grams; as each gram requires for its evaporation 0.582 calorie, the quantity of heat lost by this channel would be $400 \times 0.582 =$ 232.8 calories = 9.4 per cent.

4. *In the Evaporation of Water from the Skin.*—The quantity of water evaporated from the skin may be estimated at 660 grams, causing a loss of heat by this channel of 660 × 0.582 = 384.1 calories = 15.3 per cent.
5. *In Radiation and Conduction from the Skin.*—The amount of heat lost by this process can be indirectly determined only by subtracting the total amount lost by the above-mentioned channels from the total amount produced. Thus, 2500 — 774.4 = 1725.6 calories = 69 per cent. would represent the average amount lost by radiation and conduction.

Regulation of the Mean Temperature.—In order that the mean temperature of the body may remain practically constant, the heat dissipated must be exactly balanced by the heat liberated. Should there be any want of correspondence between the two processes, there would arise either an increase or a decrease in the mean temperature. As both heat-production and heat-dissipation are variable factors, dependent on a variety of internal and external conditions, their adjustment is accomplished by a complex self-regulating mechanism involving muscular, vascular, and secretory elements, coördinated by the nerve system. Heat-production varies in intensity and amount, in accordance with a number of conditions, but principally with variations in physiologic activity, the quantity and quality of the food, and changes in the external temperature. All physiologic and especially muscle activity is attended by chemic changes and the evolution of heat. The greater the activity, the larger is the volume of heat. Foods have different physiologic heat values. If the food consumed contains much potential energy and the quantity consumed be larger than the average daily requirements, there will be an increase in heat-production. A lowering of the external temperature, as in the winter season, leads to increased heat-production through stimulation of the nerve-centers. When all these conditions, increased muscular activity, increased amount of food of high potential energy, and a low external temperature coexist, heat-production attains its maximum, amounting to as much as 4726 calories daily (Hultgren).

Heat-dissipation varies in rapidity in accordance with variations of a number of factors, but principally with variations in the external temperature and the activity of the perspiratory apparatus. The heat is dissipated mainly by the skin, 69 per cent., in consequence of radiation and conduction and by the evaporation of the sweat. The loss by this channel as well as from the lungs is dependent for the most part on a difference of temperature of the surrounding air and of the body. If the surrounding temperature is high, there is an increase in the activity of both the circulatory and respiratory mechanisms, brought about by the central nervous system. In addition to an increased action of the heart, the blood-vessels of the skin dilate, and deliver to the surface a larger volume of blood in a given time, thus increasing the conditions favorable to radiation. The sweat-glands at the same time are stimulated to increased activity, and in consequence of the additional volumes of blood brought to the skin a larger amount of sweat is secreted, which speedily undergoes evaporation. As each gram of water for its evaporation requires 0.582 of a calorie, it is evident that increased secretion of sweat favors heat-dissipation. The nerve-centers influencing the activity of the sweat-glands may be stimulated not only reflexly, but directly by an excess of heat in the blood. If, however, the atmosphere itself possesses a high percentage of moisture, evaporation from the body is much diminished and the value of sweating as a means of lowering the body-temperature is much impaired. Evaporation is hastened by air in motion. Hastened respiratory movements and the dilatation of blood-vessels of the respiratory surface also increase the evaporation of water from the lungs and thus occasion a greater loss of heat.

If the external temperature falls there is a decrease in the physiologic activity of the skin from a contraction of the blood-vessels, a diminution of the blood-supply, and a cessation in the secretion of sweat. The blood, being prevented from coming to the surface, is retained in the deeper portion of the body, and in consequence the conditions for radiation are diminished. These variations in the cutaneous circulation in response to variations in the external temperature are brought about by the vaso-motor nerve mechanism; and as they take place with extreme promptness heat-dissipation and heat-production are quickly adjusted and the mean temperature maintained.

Radiation from the skin is modified to some extent by clothing. An excess of clothing diminishes, a diminution of clothing increases radiation. The quality of clothing is also an important factor. Wool is a poor conductor of heat but a good absorber and retainer of moisture, and hence is adapted for cold weather. Linen and cotton possess the opposite qualities, and hence are adapted for warm weather. Radiation from the skin is somewhat interfered with by subcutaneous fat, the extent of the interference being dependent on its amount.

The foregoing estimates as to the amounts of heat produced have reference only to the body in repose. When the body passes into a state of muscle activity, there is at once a notable increase in heat-production in consequence of the increase in the activity of the chemic changes which underlie body activity, as shown by the increase in the consumption of oxygen and the production of carbon dioxid. Not all of the potential energy set free, however, appears as heat; for, if the muscles are engaged in doing work a part of the energy which would otherwise manifest itself as heat is converted into mechanic motion. From the work done during a period of eight hours it has been estimated that about 500 calories are so transformed or utilized. Hirn calculated from an average of five experiments that a man weighing 67 kilos in repose produced 154.4 calories per hour and absorbed 30.7 grams of oxygen per hour; but when engaged in active muscle movements produced 271.2 calories and absorbed 119.84 grams of oxygen per hour. The increase in heat-production per hour during activity was thus almost doubled, though the sum total produced daily in which there was a working period of eight or ten hours was only about one-third more than during a day of repose. During sleep there is a greatly diminished heat-production, not more than 40 calories per hour being produced. The preceding data may be tabulated as follows (Martin):

	Day of Rest.		Day of Work.		
	Rest 16 hrs.	Sleep 8 hrs.	Rest 8 hrs.	Work 8 hrs.	Sleep 8 hrs.
Heat units (calories) produced..	2470.4	320	1235.2	2169.6	320
	2790.4		3724.8		

CHAPTER XVII.

SECRETION.

Secretion.—Secretion is a term applied to a process by which a portion of the constituents of the blood are separated from the blood-stream, by the activities of the endothelial cells of the capillary wall, as the blood flows through the capillary blood-vessels. In this process the endothelial cell is aided by the physical forces, diffusion, osmosis and filtration. The materials thus separated are collectively termed *lymph*. This separated or secreted material may be utilized in several ways:

1. For the repair of the tissues, for growth, for the liberation of energy.
2. For the elaboration or production by specialized organs of a variety of complex fluids of widely different application. The fluids thus formed are utilized for the most part to meet some special need of the body. All such fluids are termed *secretions*.

All secretions are products of the activities of epithelial cells covering a flat, or lining a more or less complexly involuted, membrane which in each instance may be termed a *secretor organ*. As the fluids are poured out on the surface of the body, they have been termed *external* secretions: *e. g.*, mucus, saliva, gastric juice, milk, sebaceous matter, etc. Within recent years it has been demonstrated that the epithelium of certain organs and particularly of those which do not possess a duct, such as the thyroid, thymus, adrenals, hypophysis, etc., also produces certain specific constituents which are reabsorbed into the blood, and which in some unknown but yet favorable way influence the general nutrition. To such products of these organs the term *internal* secretions has been given.

The blood, in addition to its nutritive constituents, contains a number of principles, derived from the tissues, which are to be regarded as waste products, the outcome of the katabolic activity of the tissues and of no further use to the body. If retained, they would seriously if not fatally interfere with the normal physiologic activities of the different tissues. They are therefore removed by specialized organs after their separation from the blood-stream. The waste products in solution thus removed are not capable of being utilized for any special purpose, and are therefore termed *excretions: e. g.*, urine, perspiration, etc. Excretion, however, is performed by the activities of epithelial cells aided by the physical forces of diffusion, osmosis and filtration; and though a distinction is made between the two classes of fluids, no sharp line can be drawn between the cell processes which take place in secretor and excretor organs.

All secretor organs may be divided into—

1. Epithelial.
2. Reticular and vascular, the latter term indicating merely their relation to blood-vessels.

The Epithelial Secretor Organs.—The epithelial secretor organ consists primarily of a thin delicate homogeneous membrane, one side of which is covered with a layer of epithelial cells and the other side of which is closely invested by a network of capillary blood-vessels, lymph-vessels and nerves. Though the epithelial cells have a general histologic resemblance one to another, their physiologic function varies in different situations, in accordance probably with their ultimate chemic structure, a fact which determines the difference in the character of the secretions.

The *epithelial secretor organs* may consist of a single layer of cells or a group of cells, and may be subdivided into—

1. Secreting membranes.
2. Secreting glands.

The **secreting membranes** are the mucous membranes lining the gastro-intestinal, the pulmonary, and the genito-urinary tracts, and the serous membranes lining closed cavities, such as the pleural, pericardial, peritoneal, and synovial membranes.

The *mucous membranes* are soft and velvety in character and are composed of a condensed connective tissue forming a basement membrane beneath which is a layer of blood-vessels and muscle-fibers, and on which is a layer of epithelium, the histologic as well as physiologic characters of which vary in different situations. The mucus secreted by the various epithelial forms will very naturally possess a somewhat different composition, according to the locality in which it is formed. In a general way it may be said that mucus is a pale, semitransparent, alkaline fluid, containing leukocytes and epithelial cells. It is composed chemically of water, mineral salts and an albuminoid body, *mucin*, to the presence of which it owes its viscidity. Much of the mucus is secreted by the goblet cells on the surface of the mucous membranes. The principal varieties of mucus are the nasal, bronchial, vaginal, urinary, gastro-intestinal.

The *serous membranes* are composed of thin membrane formed by a condensation of connective tissue and covered by a single layer of large, flat, nucleated cells with irregular margins. These membranes enclose what are practically large lymph sacs or spaces, and the fluid they contain resembles lymph in all respects and is practically identical with it. It serves to diminish friction when the viscera they enclose move over one another. The most important of the serous membranes are the pleural, pericardial, and peritoneal.

The *synovial membranes* in and around joints resemble serous membranes. The cells covering them, however, secrete a clear, colorless fluid resembling lymph, but differing from it in containing a mucin-like substance, a nucleo-albumin, which imparts to it considerable viscidity. This synovial fluid serves to diminish friction between the opposing surfaces of the bones as they glide over one another during movement.

Other secretions, such as the aqueous and vitreous humors of the eye, the fluid of the internal ear, the cerebrospinal fluid, etc., will be considered in connection with the organs with which they are associated, as have been the digestive secretions.

The **secreting glands** are formed of the same histologic elements as the secreting membranes. They are formed by an involution of the mucous membrane or skin the epithelium of which is variously modified structurally and functionally in the various situations in which they are formed. Like the membranes themselves, the glands are invested by capillary blood-vessels and supplied with lymph-vessels and nerves, of which the latter are in direct connection with the blood-vessels and epithelial cells. The interior of each gland is in communication with the free surface by one or more passageways known as ducts.

These glands may be classified according as the involution is cylindrical or dilated as—

1. Tubular. The *tubular* glands may be simple—*e. g.*, sweat-glands, intestinal glands, fundus glands of the stomach; or compound —*e. g.*, kidney, testicle, salivary, and lachrymal glands.
2. Alveolar. The *alveolar* glands may also be simple—*e. g.*, the sebaceous glands, the ovarian follicles, meibomian glands; or compound, as the mammary glands and salivary glands.

For the production of a secretion it is necessary that the plasma of the blood, the common material, be delivered to the lymph-spaces with which the epithelial cells are in close relation. The processes involved in the passage of the plasma across the capillary wall have already been considered in connection with the production of lymph. They include the physical processes, diffusion, filtration, and osmosis, combined with a secretory activity of the cells of the capillary wall. The question as to which of these processes is the more active is yet a subject of investigation.

As the chemic composition and the chemic features of the organic constituents of all secretions have been demonstrated to be the outcome of metabolic processes going on within the epithelial cells, it must be assumed at least that these differences are correlated with differences in the histologic features and molecular structure of the epithelium. The discharge of the secretion is, as a rule, intermittent; that is, there are periods of activity on the part of the gland followed by periods of inactivity or rest. In rest more especially the epithelial cells, after the assimilation of lymph, accumulate within themselves such characteristic products as globules of mucin, granules which apparently are the antecedents of the digestive enzymes, granules of glycogen, globules of fat, sugar, and proteid, as in the case of the mammary gland. In how far all these compounds are the result of secretor activity or of a cell degeneration and disintegration it is impossible to state in the light of present knowledge. During the period of gland rest the blood-supply to the gland is merely sufficient for nutritive purposes. When the occasion arises for gland activity, the blood-vessels, under the influence of the vaso-motor nerves, dilate and deliver to the gland an amount of blood far beyond that required for nutritive purposes. As a result the gland becomes red and vascular and the blood emerging by the veins frequently retains its customary arterial color. The increased blood-supply favors a rapid transudation of water and salts into the lymph-spaces from which they are speedily absorbed and transmitted by the epithelial cells into the interior of the gland lumen. Coincident with the passage of water through the cell, the organic constituents are extruded from the end of the cell bordering the lumen to become dissolved, or in the case of fat to be suspended, in the water. The secretion thus formed accumulates and with the rise of pressure which inevitably follows it at once passes into the ducts to be discharged on the surface of the mucous membrane or skin, as the case may be.

Influence of the Nerve System.—The activity of every gland is controlled by nerve-centers situated in the central nerve system. These centers may be excited to activity either by impressions made on the peripheral terminations or by emotional states, or, possibly, by changes in the composition of the blood itself. As a rule, all normal secretion is a reflex act involving the usual mechanism: viz., a sentient surface (skin, mucous membrane, or sense-organ), an afferent nerve, an emissive cell from which emerges an efferent nerve to be distributed to a responisve organ, the gland epithelium.

For the production of the secretion by the epithelial cell it is believed by some experimenters that two physiologically distinct, efferent nerve-fibers are involved—one stimulating the production of the organic constituents (*trophic* nerves), the other stimulating the secretion of water and inorganic salts (*secretor* nerves). The evidence for the influence of the nerve system on secretion and the mode of connection of the nerve-fibers with the gland-cells have been alluded to (page 163) and will again be in subsequent chapters.

The **reticular and vascular glands,** though not possessing any common histologic features, are grouped together merely for convenience, and will be considered in a separate chapter in connection with the problems of *internal* secretion.

MAMMARY GLANDS.

The **mammary glands,** which secrete the milk, are two more or less hemispheric organs situated in the human female on the anterior surface of the thorax. Though rudimentary in childhood, they gradually increase in size as puberty approaches. The gland presents at its convexity a small conical eminence termed the mammilla or nipple, surrounded by a circular area of pigmented skin, the areola. The gland proper is covered by a layer of adipose tissue anteriorly and is attached posteriorly to the pectoral muscles by a network of fibrous tissue.

During utero-gestation the mammary glands become larger, firmer, and more lobulated; the areola darkens and the blood-vessels, especially the veins, become more prominent. At the period of lactation the gland is the seat of active histologic and physiologic changes correlated with the production of milk. At the close of lactation these activities cease, the glands diminish in size, undergo involution, and gradually return to their former non-secreting condition.

Structure of the Mammary Gland.—Each mammary gland consists of an aggregation of some 15 or 20 irregular pyramidal lobes, each of which is surrounded by a framework of fibrous tissue. This tissue affords support for blood-vessels, lymphatics, and nerves. Each lobe is provided with a single excretory duct, the lactiferous duct, which as it approaches the areola expands into a fusiform ampulla or reservoir. At the base of the nipple the ampullæ contract to form some 16 or 18 narrow ducts, which, ascending the nipple, open by constricted orifices 0.5 mm. in diameter on its apex (Fig. 206).

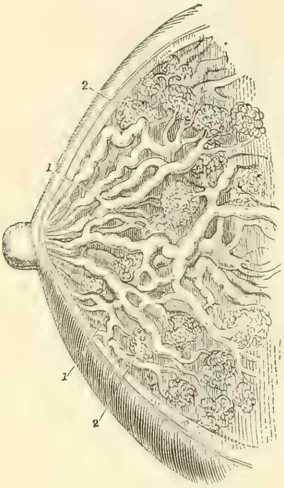


FIG. 206.—MAMMARY GLAND. 1. Lactiferous ducts. 2. Lobuli of the mammary gland.

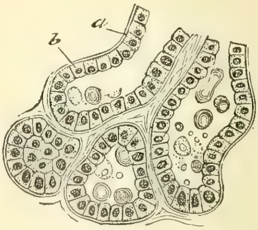


FIG. 207.—ACINI OF THE MAMMARY GLAND OF A SHEEP DURING LACTATION. *a.* Membrana propria. *b.* Secretory epithelium.

On tracing the lactiferous duct into a lobe, it is found to divide and subdivide into a number of branches, which pass into smaller masses—the lobules. The lobule in turn is composed of a large number of tubular acini or alveoli, the final terminations of the lobular ducts. Each acinus consists of a basement membrane lined by a single layer of low cuboidal epithelial cells (Fig. 207). Externally the acinus is surrounded by blood-vessels, nerves, and lymphatics.

MILK.

Milk as obtained during active lactation is an opaque bluish-white fluid, almost inodorous, with a sweet taste, an alkaline reaction, and a specific gravity of from 1.025 to 1.040. Examined microscopically, it is seen to consist of a clear fluid, the milk *plasma*, holding in suspension an enormous number of small, highly refractive oil-globules, which measure on the average about $\frac{1}{10000}$ of an inch in diameter. It has been asserted by some observers that each globule is surrounded by a thin proteid envelope which enables it to maintain the discrete form. This, however, is at present disbelieved.

The quantity of milk secreted daily by the human female averages about 1200 c.c.

Chemic analysis has shown that the milk of all the mammalia consists of all the different classes of nutritive principles, though in different proportions, which are necessary to the growth and development of the body. The only exception appears to be an insufficient amount of iron for the formation of the coloring-matter of the blood, the hemoglobin.

Caseinogen is the chief proteid constituent of milk. Associated with it, however, are two other proteids, lactalbumin and lactoglobulin, both of which are present in but small quantity. When milk is treated with acetic acid, sodium chlorid, or magnesium sulphate to saturation, the caseinogen is *precipitated* as such, and after the removal of the fat with which it is entangled may be collected by appropriate chemic methods. On the addition of rennet prepared from the mucous membrane of the calf's stomach, which contains the enzyme rennin or pexin, the caseinogen undergoes cleavage into an insoluble proteid, casein or tyrein, and a small quantity of a new soluble proteid. To this process the term *coagulation* has been given. The presence of calcium phosphate appears to be essential to this process, inasmuch as it does not take place if the milk be completely decalcified by the addition of potassium oxalate. After coagulation, the more or less solid mass of milk separates into a liquid portion, the serum, and a solid portion, the coagulum. The former, generally termed whey, consists of water, salts, lactalbumin, sugar; the latter, the curd, consists of the casein and entangled fat. Boiling the milk retards and even prevents the coagulation by rennet, owing to the precipitation of the calcium phosphate. When milk is taken into the stomach, it is probable that the rennin coagules the caseinogen in a manner similar to, if not identical with, this process, which appears to be essential to the normal digestion of the milk.

The **fat** of milk is more or less solid at ordinary temperatures. It is a compound of olein, palmitin, and stearin with small quantities of butyrin and caproin. The melting-point of butter varies between 31° and 34° C. When milk is allowed to stand for some time, the fat-globules rise to the surface and form a thick layer known as cream.

Churning the milk or cream causes the fat-globules to run together and form a coherent mass termed butter.

Lactose is the particular form of sugar characteristic of milk. It belongs to the saccharose group and has the following composition: $C_{12}H_{22}O_{11}$. Though incapable of undergoing fermentation by the action of the yeast plant, it is readily reduced by the Bacillus acidi lactici to lactic acid and carbon dioxid, the former of which imparts to milk an acid reaction and a sour taste. With the accumulation of the lactic acid the caseinogen is precipitated as a more or less consistent mass.

The **inorganic salts** of milk are chiefly potassium, sodium, calcium, and magnesium phosphates and chlorids. Iron is also present in small amount. The following table of Bunge gives the quantitative amounts of these constituents in both human and cow's milk:

In 1000 Parts.	Potassium.	Sodium.	Calcium.	Magnesium.	Iron Oxid.	Phosphoric Acid.	Chlorin.
Human milk,	0.78	0.25	0.33	0.06	0.0036	0.47	0.43
Cow's milk,	1.76	1.11	1.59	0.21	0.0030	1.97	1.69

Mechanism of Milk Secretion.—During the time of lactation the mammary gland exhibits periods of secretory activity which alternate with periods of repose. Coincidently with these periods certain histologic changes take place in the secreting epithelium At the close of a period of active secretion and after the discharge of the milk each acinus presents the following features: The epithelial cells are short, cubical, nucleated, and border a relatively wide lumen, in which is found a variable quantity of milk. After the gland has rested for some time active metabolism again begins. The cells grow and elongate; the nucleus divides into two or three new nuclei; constriction takes place and the inner portion is detached and discharged into the lumen of the acinus. During the time these changes are taking place oil-globules make their appearance in the cell protoplasm, some of which are discharged separately into the lumen, while others remain for a time associated with the detached portion of the cell (Fig. 208). From these histologic changes it is inferred that the caseinogen and fat are products of the metabolism of the cell protoplasm and not derived directly through the lymph from the blood. The lactose apparently has a similar origin, as appears from the fact that it is not found either in the blood or any other tissue, and that it is formed independently of carbohydrate food. The water, and especially the inorganic salts, are the result of secretory activity rather than of diffusion and filtration. This is rendered probable from the fact that the proportions of the inorganic salts of milk are more closely allied to those of the tissues of the new-born child than to blood. With the passage of the water and salts into the lumen of the acinus the proteids undergo disintegration and solution and the liquid assumes the characteristics of milk.

The discharge of milk is occasioned by the suction efforts on the part of the child, aided by atmospheric pressure and the contractions of the non-striated muscle-fibers of the lactiferous ducts.

Influence of the Nerve System.—Judging from analogy, it is probable that the secretion of milk is regulated by influences emanating from the nerve system, though the exact nerve-channels for the transmission of such influences have not been determined experimentally. Various attempts have been made to isolate and study these nerves, but the results are inconclusive. It is well known that emotional states on the part of the mother modify the quantity as well as quality of milk, indicating a connection between the gland-cells and the central organs of the nerve system. Nerve terminals have been discovered in and around the epithelial cells—a fact which supports this view.

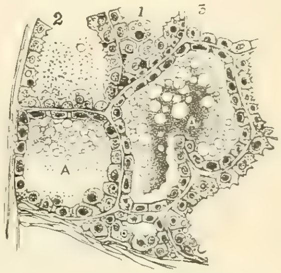


FIG. 208.—SECTION OF THE MAMMARY GLAND OF A CAT IN THE EARLY STAGES OF LACTATION. A. Cavity of alveoli filled with granules and globules of fat. 1, 2, 3. Epithelium in various stages of milk-formation.—(*Yeo.*)

Colostrum.—Within a day or two after parturition the alveoli become filled with a fluid which in some respects resembles milk and which has been termed colostrum. This is a watery fluid containing disintegrated epithelial cells, fat-globules, as well as colostrum corpuscles, which are probably emigrated leukocytes. Colostrum is distinguished from milk in being richer in sugar and inorganic salts. It is said to possess constituents which act as a laxative to the young child.

THE LIVER.

The **liver** is a large gland situated in the upper and right side of the abdominal cavity, where it is held in position largely by ligaments formed by reduplications of the peritoneal investment. In the adult it weighs, freed of blood, from 1300 to 1700 grams. The liver is connected with the duodenal portion of the intestine by the hepatic duct. It receives blood both from the hepatic artery and from the portal vein, and in this respect differs from all other glands in the body. The epithelial structures of the liver are inclosed by a firm fibrous membrane, known as Glisson's capsule. At the transverse fissure it invests and follows the blood-vessels, which there enter, in all their ramifications through the gland.

Structure of the Liver.—The liver is composed of an enormous number of small masses, rounded, ovoid, or polygonal in shape, called lobules, measuring about one millimeter in diameter and separated from one another by a narrow space in which are to be found blood-vessels, lymphatics, hepatic ducts, supported by connective tissue. In the pig this space and its contained elements is quite distinct, sharply marking out the border of the lobule (Fig. 209). This is not so apparent in man. Each lobule is made up of irregular or polygonal shaped cells measuring about 30 to 40 micromillimeters in diameter. These cells are arranged in a radial manner from the center to the circumference of the lobule (Fig. 210). Each cell possesses one and at times two nuclei. There is no evidence for the existence of a distinct cell-wall. The cell protoplasm frequently contains globules of fat, granules of a proteid nature, granules of glycogen, pigment material, etc. The appearance presented by the cell will vary considerably, according to the time it is observed. Thus there may be a complete absence of these constituents, when the cell may present a series of vacuoles separated by bands of protoplasm. The cells are the secreting structures of the liver, and hence are in close relation with capillary blood-vessels, lymphatic spaces, nerves, and irregular channels or passageways. The latter running between the epithelial cells may be compared to the lumen of other secreting glands.

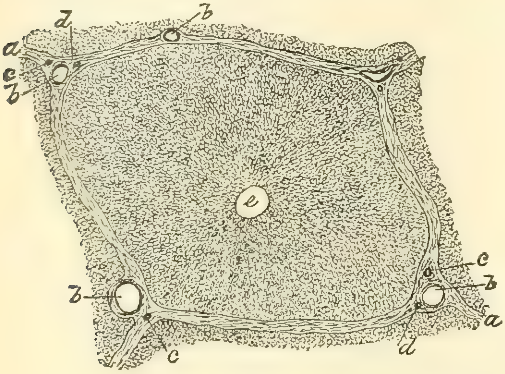


Fig. 209.—Section of Liver of Pig, showing very Diagrammatically the Lobules. *a.* Interlobular connective tissue. *b, c.* Branches of portal vein and of hepatic artery. *d.* Bile-ducts. *e.* Intralobular vein.—(*Piersol.*)

Blood-vessels and Their Distribution.—The blood-vessels which are in relation with the liver are:

1. The portal vein.
2. The hepatic artery.
3. The hepatic vein.

The portal vein and the hepatic artery enter the liver at the transverse fissure. After penetrating its substance they divide and subdivide into smaller and smaller branches, which ultimately occupy the space between the lobules, completely surrounding and limiting them. From their situation they are termed *interlobular* veins and arteries.

The interlobular veins give off small capillary vessels which penetrate the lobule at all points of its surface. These capillaries, though frequently anastomosing, form a radial meshwork which converges toward the center of the lobule. In the meshes of this plexus are found, arranged in a corresponding radial manner, the liver cells. The interlobular arteries are distributed to the walls of the portal vein, to the connective tissue, and finally terminate in the portal vein capillaries. The intralobular capillaries thus receive and transmit blood which is an admixture of both arterial and venous blood. In the center of each lobule there is a large vein, formed by the union of the intralobular capillaries, known as the *intralobular* vein, which collects all the blood of the lobule and transmits it through the lobule to an underlying or sublobular vein (Fig. 211). These latter vessels, uniting and reuniting, ultimately form the hepatic vein, which empties the blood into the inferior vena cava.

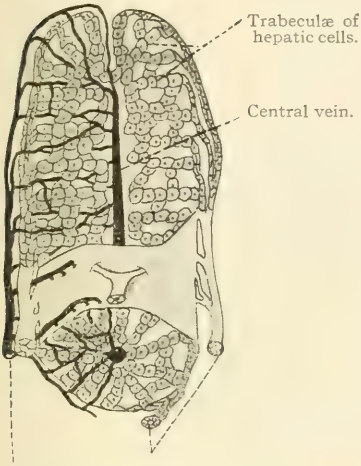


FIG. 210.—SCHEME OF A HEPATIC LOBULE, REPRESENTED IN TRANSVERSE SECTION BELOW AND, BY PARTIAL LEVELING, IN LONGITUDINAL SECTION ABOVE. In the left half the blood-vessels are drawn; in the right half only the cords of hepatic cells. × 20. —(*Stöhr.*)

Bile Capillaries and Hepatic Ducts.—The bile capillaries are narrow channels which penetrate the lobule in all directions and are generally found running along the sides of the cells. These channels, which are devoid of walls, receive from the cells some of the products of their secretory activity, and hence are comparable to the lumen of the alveoli of other secreting glands. At the periphery of the lobules the bile capillaries communicate with larger channels which are the beginnings of the hepatic or bile-ducts lying in the interlobular spaces. The interlobular bile-ducts possess a distinct wall lined by flattened epithelium. There is, however, no distinct line of demarcation between the cells of the interlobular ducts and the secreting cells of the liver proper, as the two blend insensibly, the one into the other. As the hepatic ducts increase in size they gradually acquire the structure characteristic of the main hepatic duct: viz., a mucous, a muscle, and a fibrous coat.

Nerves.—Experimental investigations have demonstrated that the liver is supplied with nerves derived from the central nerve system. The route of these nerves is probably by way of the splanchnics and the vagi. Many of the nerves which enter the liver are vaso-motor in function; as to whether others are secretory in character is yet a subject of investigation. It has been asserted that nerve terminals have been demonstrated running between the cells and even penetrating their substance. This fact would indicate that the metabolic processes of the liver are under the control of the central nerve system.

Functions of the Liver.—The anatomic and histologic peculiarities of the liver would indicate that it has a variety of relations to the general processes of the body. Experimental investigation has brought some of these relations to light. Though its physiologic actions are not yet wholly understood, it may be said that it—

1. Secretes bile.
2. Produces and stores glycogen.
3. Assists in the formation of urea.

Secretion of Bile.—The physical properties and chemic composition of the bile have already been considered (page 202). The characteristic salts of the bile, sodium glycochlate and taurocholate, do not pre-exist in the blood, and therefore must be formed by the liver cells out of materials derived from the blood of the intralobular capillaries. The antecedents of the bile salts, glycocoll and taurin, are crystallizable nitrogenized compounds, and known chemically as amido-acetic and amido-ethylsulphonic acids. Their chemic composition indicates that they are derivatives of the proteids or the albuminoids, though the intermediate stages in their production are unknown. The origin of the cholalic acid with which they are combined is equally obscure. The bile salts as they are found in the bile are produced in the liver cells by metabolic activity.

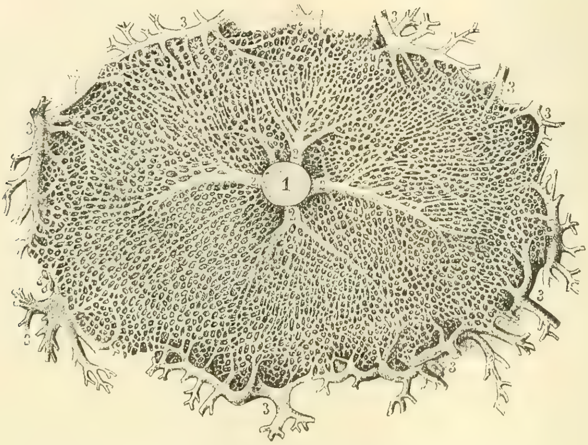


FIG. 211.—TRANSVERSE SECTION OF A SINGLE HEPATIC LOBULE. 1. Intralobular vein, cut across. 2, 2, 2, 2. Afferent branches of the intralobular vein. 3, 3, 3, 3, 3, 3, 3, 3, 3. Interlobular branches of the portal vein, with its capillary branches, forming the lobular plexus, extending to the radicles of the intralobular vein.—(*Sappey.*)

The primary coloring-matter of the bile, bilirubin, has been shown to be a derivative of hematin, a product of the disintegration of hemoglobin. It is supposed that the liver cells bring about this change by combining water with hematin, with the abstraction of iron. The product thus formed is bilirubin, which is excreted, while the iron is for the most part retained.

Cholesterin is a waste product derived largely from the nerve-tissue. It is brought to the liver and simply excreted by the cells. The remaining constituents of the bile, water and inorganic salts, are secreted here as in all other glands.

When once formed, the liver cells discharge these various compounds into the channels by which they are surrounded; they then pass into the open mouths of the bile-ducts at the periphery of the lobules. Under the increasing pressure which arises from the secretion and accumulation of bile, this fluid flows from the smaller into the larger bile-ducts, and finally is emptied either directly into the intestine or into the gall-bladder, where it is stored until required for digestive purposes. The secretion of bile, as observed by means of a biliary fistula, is continuous and not intermittent, though the rate of flow is subject to considerable variation.

The liver cells, as far as the secretion of bile is concerned, appear to be independent of the nerve system. Their activity, however, is stimulated by the increased blood-supply which arises during digestion in consequence of the dilatation of the intestinal vessels, since it is at this period that the rate of discharge is the greatest. The same results have been shown by experiment. Thus, division of the splanchnic nerves is followed by an increased discharge of bile, apparently due to the dilatation of the portal vessels; stimulation of their peripheral ends is followed by a decreased discharge of bile in consequence of the contraction of the portal vessels. The bile salts appear to be the most efficient stimulants to the activity of the liver cells, for their administration and absorption is followed by an increase not only in the amount of water, but of the inorganic salts and other solid constituents as well.

The flow of bile from the bile capillaries to the main hepatic duct, though primarily dependent on differences of pressure, is aided by the contraction of the muscular walls of the bile-ducts and the inspiratory movements of the diaphragm. Any obstacle to the discharge of bile leads to its accumulation, a rise of pressure beyond that of the capillary blood-vessels, and a reabsorption by the lymph-vessels of the bile constituents. After their discharge into the blood from the thoracic duct these constituents are deposited in part in various tissues, giving rise to the phenomena of jaundice, and in part are eliminated in the urine.

The Production of Glycogen.—In 1857 Bernard discovered the fact that the liver normally during life produces a sugar-forming substance, analogous in its chemic composition to starch, to which he gave the name glycogen. This substance can be obtained by the following method: Small pieces of the liver of an animal recently killed, preferably after a meal rich in carbohydrates, are placed in acidulated boiling water for a few minutes; then rubbed up in a mortar with sand, again boiled, after which the proteids are removed by filtration. The filtrate thus obtained is opalescent and resembles a solution of starch. The glycogen may be precipitated from this solution with alcohol as a white amorphous powder, soluble in water. Chemic analysis shows that it consists of $C_6H_{10}O_5$, or a multiple of it.

When either the original solution obtained by boiling or a solution of this amorphous powder is treated with iodin, it strikes a port-wine color. When digested with saliva, pancreatic juice, or boiled with dilute acids, the solution becomes clear, and testing with Fehling's solution reveals the presence of sugar.

If the liver be allowed to remain in the body of an animal for a period of twenty-four hours before the decoction is made as above described, it will be found that the solution contains only a small amount of glycogen but a relatively large amount of sugar. The inference drawn is that after death the glycogen is transformed by some agent, possibly a ferment, into sugar (dextrose).

The presence of glycogen in the liver cells can be shown microscopically in the form of discrete hyaline and refractive granules. As they are soluble in water they can be readily dissolved out from the cells, leaving small vacuoles separated from one another by strands of cell substance. The amount of glycogen in a well-fed animal varies from 1.5 to 4 per cent. of the total weight of the liver. The production of glycogen is dependent very largely on the consumption of carbohydrates, the greater the amount of sugar and starch in the food, the greater being the production of glycogen. On a pure proteid diet it is still produced, though in small amounts.

Glycogen is also found in muscles, placenta and embryonic tissues generally. Muscles contain from 0.5 per cent. to 1 per cent. and as they amount to about 40 per cent. of the weight of the body, 70 kilograms, they contain from 140 to 280 grams of glycogen. During periods of prolonged activity of the muscles the percentage of glycogen rapidly diminishes, a fact which leads to the inference that it is the source in large part of the energy expended by the muscle. During rest the percentage of glycogen again rapidly increases until the normal percentage is regained. The source of the muscle glycogen is undoubtedly the liver in which it is temporarily stored.

The facts connected with the formation of glycogen, as well as its disposition as at present generally accepted, may be stated as follows: The dextrose into which the carbohydrates are converted by the action of the digestive fluids is absorbed into the blood of the portal vein and carried direct into the liver, where by the action of the cells it is abstracted, dehydrated, and temporarily deposited under the form of the non-diffusible body glycogen. At a subsequent period and in proportion to the needs of the system the liver cells, through the agency of a ferment, transform the glycogen into dextrose, return it to the circulation, by which it is transported to the systemic capillaries, where it disappears. The blood of the hepatic vein therefore contains more sugar than the blood of any other part of the body, and the blood of the arteries more than the blood of the other veins. Should there be a failure on the part of the liver cells to abstract the sugar, it would pass through the liver into the general circulation, from which it would be eliminated by the kidneys. The final fate of the sugar is uncertain. It is, however, probable that after its delivery to the muscles, for example, it may be directly oxidized, or stored as glycogen or possibly utilized in the formation of living material. Ultimately, however, through oxidation it yields heat, and contributes to the production of muscle energy.

In opposition to this view, Dr. Pavy, after years of accurate experimentation, states that the blood on the cardiac side of the liver never under normal circumstances contains a larger percentage of sugar than is to be found in any part of the circulation, except in the portal vein. He states that glycogen is never reconverted into sugar, and denies that the liver produces sugar, to be discharged into the blood; that the function of the liver is merely to arrest the passage of sugar, and so to shield the general circulation from an excess; that the sugar which arises in the liver after death is a post-mortem product and not an illustration of what takes place during life. Dr. Pavy, having apparently demonstrated the glucoside constitution of proteid material in general, accounts for the presence of glycogen in muscles and other tissues on the assumption that during the cleavage of the proteid molecule the carbohydrate element is set free and temporarily stored as glycogen. He thus accounts for the production of sugar in the body, even in the absence of all sugar and starch from the food. Pavy believes that the glycogen produced in the liver is utilized in the formation of fat and the synthesis of complex proteids necessary to the construction of the tissues.

The Influence of the Nerve System.—The results of various experimental investigations indicate that the production of sugar from the glycogen in the liver is influenced by the activities of the nerve system. It was discovered by Bernard that puncture of the floor of the fourth ventricle, at a point between the acoustic and vagus nerves, near the middle line, is followed within an hour or two by the appearance of sugar in the urine, which lasted for from five to six hours in the rabbit and from two to three or even seven in the dog. For this reason Bernard gave to this area the name of "diabetic area."

Coincident with the appearance of sugar in the urine (glycosuria) there is an increase in the percentage of sugar in the blood (hyperglycemia). The liver at the same time contains a higher percentage of sugar than normally. Apparently the initial step in this series of phenomena is an increased conversion of glycogen into sugar. This supposition receives support from the fact that the degree of the hyperglycemia, and the subsequent glycosuria, will depend on the amount of glycogen previously in the liver. If the animal has been well fed on carbohydrates, the resulting glycosuria will be pronounced; if, on the contrary, it has been allowed to fast for several days, the glycosuria will be slight.

Assuming that the nerve-cells which constitute the diabetic area influence the conversion of glycogen into sugar, the question arises as to whether the puncture destroys the nerve-cells, or whether it stimulates them to increased activity. The results of experiment lead to the latter supposition. Thus if the vagus nerve is divided in the neck and its central end stimulated there is developed a glycosuria. Stimulation of other sensor nerves has a similar effect. As stimulation of the vagus has the same effect as the puncture, the inference is that the center is normally excited to physiologic activity by impulses reflected from some surface or organ in the peripheral distribution of this nerve.

If the nerve-cells in the diabetic area regulate the production of sugar in the liver, the further question arises as to the pathway through which the nerve impulses emanating from them reach the liver, whether by way of the vagi or by way of the spinal cord and splanchnic nerves. That it is not by way of the vagi is shown by the fact that the glycosuria established by the puncture does not disappear when they are divided; that it is by way of the spinal cord, as far at least as the first dorsal nerve, and subsequently the splanchnic nerves, is indicated by the fact that a cross-section of the spinal cord above this level, destruction of the upper three dorsal roots as well as division of the splanchnic nerves prevents the development of the glycosuria which follows puncture of the medulla. Though stimulation of the upper dorsal (preganglionic) nerve-fibers gives rise to glycosuria, yet, contrary to expectation, stimulation of the splanchnic (post-ganglionic) nerve-fibers does not have the same effect. This may be due, however, to changes in the relation of the capillary blood-vessels to the liver cells or to the character of the stimulus employed.

A further question arises as to whether the nerve impulses which pass from the diabetic center to the liver are vaso-motor in character and exerting their effect on the blood-vessels, or whether they are secretor in character and exerting their effect on the liver cell. Bernard was of the opinion that they are vaso-motor in character and that the diabetic area was a part of the general vaso-motor center. More recent investigators are of the opinion that they are secretor in character, for the reason that whether the blood-pressure rises from a stimulation of the central end of the divided vagus, or falls from a stimulation of the depressor nerve, in each instance there follows a glycosuria.

If the production of sugar in the liver is a reflex act as Bernard supposed, taking place through a mechanism consisting of an afferent pathway, the vagus nerve, and an efferent pathway consisting of the spinal cord and splanchnic nerves, the question arises as to the seat of action of the stimulus. This Bernard located in the lungs, for the reason that though division of the vagus in the neck checks the production of the sugar, division below the origin of the pulmonary branches had no such effect.

Diabetes.—Diabetes is a chronic disease characterized by the appearance of sugar in the urine in variable amounts. This pathologic condition has usually been associated with derangements of the glycogen function of the liver, though doubtless derangements of other organic functions will produce the same condition. At the present time it is believed that the excretion of sugar by the kidneys depends on two causes: (1) An ineffectual abstraction and storage of sugar due to some impairment in the activity of the liver cells; (2) a rapid cleavage of the proteid constituents of the tissues, in consequence of some profound alteration in the nutritive process, whereby their glucose radicals are liberated in unusual amounts. The physiologic mechanism by which the normal metabolism of the carbohydrates is regulated is unknown. That it is complex in character is shown by the phenomena which follow not only puncture of the medulla, but also removal of the pancreas and the administration of various toxic agents.

Removal of the pancreas from the body of a dog or other animal is at once followed by a rise in the percentage of sugar in the blood and its elimination by the kidneys. In a short time acetone, aceto-acetic and oxybutyric acids make their appearance, attended by the usual symptoms characteristic of glycosuria in man. The quantity of sugar excreted and the gravity of the attendant symptoms may be much diminished by allowing a portion of the gland to remain *in situ*. even though its capacity for the production of pancreatic juice is entirely abolished. Transplantation of the pancreas to the subcutaneous tissue or to the abdominal cavity will practically prevent the glycosuria. The explanations which have been offered as to the manner in which the pancreatic tissue prevents and its absence gives rise to the excretion of sugar are purely hypothetical. It has been claimed by some investigators that the pancreas secretes a specific material, which enters the blood and promotes oxidation of the sugar. In the absence of this material the sugar accumulates, and is finally eliminated by the kidneys. Since the discovery of the islands of Langerhans it has been suggested by some investigators that the production of the material which regulates carbohydrate metabolism should be attributed to them rather than to the pancreas as a whole. The sugar excreted doubtless in part comes from the glycogen of the liver, as this disappears in a short time. But as sugar continues to be excreted, even though all carbohydrates be withdrawn from the food, the conclusion is justifiable that it arises in consequence of increased proteid metabolism. This supposition is strengthened by the fact that the quantity of urea excreted rises and falls with the quantity of sugar excreted.

Phloridzin, a glucoside obtained from the root bark of the cherry and plum tree, gives rise to the appearance of sugar in the urine, in amounts beyond that which might come from the glucose normally present in the blood or from the glycogen of the liver. As there is a concomitant increase in the amount of urea excreted, the supposition is that phloridzin increases proteid metabolism.

Curara, in doses sufficient to paralyze the muscles, also gives rise to the appearance of sugar in the urine. This is not due, however, to an increased production on the part of the liver, but rather to a want of consumption on the part of the muscles, due to their inactivity. The accumulation of the sugar in the blood which takes place for this reason leads very promptly to its removal by the kidneys.

The Formation of Urea.—It is now generally believed that the liver is the most active of all the organs which may be engaged in the production of urea. This belief is based on numerous physiologic and pathologic data. The compounds out of which the hepatic cells construct urea have been for chemic reasons asserted to be the ammonium salts, *e. g.*, the carbonate, lactate, carbamate, which are constantly present in the blood. These salts, which result from proteid metabolism, may be absorbed from the tissues or from the intestines carried to the liver, and there synthesized to urea. This supposition is supported by an experiment as follows: The liver of an animal recently living is removed from the body and its vessels perfused continuously with blood (the urea content of which is known) containing the ammonium salts. An analysis of this blood shows, after a time, a diminution of these salts, and a large increase in the amount of the urea. After the establishment of an Eck fistula (the union of the portal vein with the ascending vena cave whereby the liver is largely excluded from acting on products absorbed from the intestines) there is a marked diminution in the production of urea while the ammonia content of the urine largely increases. The leucin and tyrosin which result from the prolonged action of pancreatic juice on hemi-peptone are also capable of being converted to urea by the hepatic cells, and in all probability are so disposed of. Destructive diseases of the liver—*e. g.*, acute yellow atrophy, suppuration, cirrhosis—largely diminish the production of urea, but increase the quantities of the ammonium salts in the urine. The same is true when the liver cells are destroyed during acute phosphorus-poisoning.

VASCULAR OR DUCTLESS GLANDS.

INTERNAL SECRETIONS.

The metabolism of the body generally, as well as that of individual organs, has been shown to be related not only to the physiologic activity of such organs as the liver and pancreas, but also to the activity of the so-called vascular or ductless glands. The influence of the pancreas in regulating the production of glycogen by the liver, and the influence of the liver in the maintenance of the general metabolism through the production of glycogen and the formation of urea, are now established facts. That the vascular or ductless glands to an equal extent, though perhaps in a different way, assist in the maintenance of physiologic processes, appears certain from the results of animal experimentation. The explanation given for the influence of these glands is that they produce specific substances, which are poured into the blood or lymph and carried direct to the tissues, to the activities of which they appear to be essential; for without these substances the nutrition of the tissues declines and in a short time a fatal termination ensues.

Inasmuch as these partly unknown substances are formed by cell activity and are poured into the interstices of the tissues, they have been termed "internal secretions." Though the term internal secretions is applicable to all substances which arise in consequence of tissue metabolism, and which, after being poured into the blood, influence in varying degrees and ways physiologic processes, yet the term in this connection will be applied only to the secretions of the thyroid gland, hypophysis cerebri, and adrenal bodies.

Thyroid Gland.—The thyroid gland or body consists of two lobes situated on the lateral aspect of the upper part of the trachea (Fig. 212). Each lobe is pyriform in shape, the base being directed downward and on a level with the fifth or sixth tracheal ring. The lobe is about 50 mm. in length, 20 mm. in breadth, and 25 mm. in thickness. As a rule, the lobes are united by a narrow band or isthmus of the same tissue. The gland is reddish in color, and abundantly supplied with blood-vessels and lymphatics.

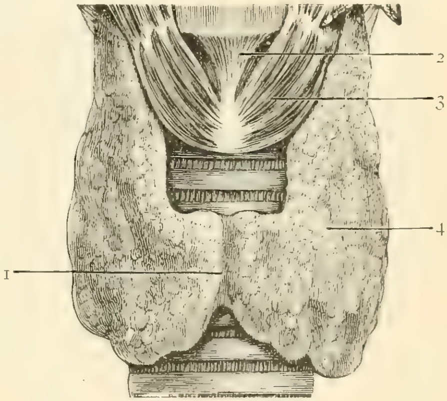


FIG. 212.—VIEW OF THYROID BODY. 1. Thyroid isthmus. 2. Median portion of crico-thyroid membrane. 3. Crico-thyroid muscle. 4. Lateral lobe of thyroid body.—(*After Morris.*)

Microscopic examination shows that the thyroid consists of an enormous number of closed sacs or vesicles, variable in size, the largest not measuring more than 0.1 mm. in diameter (Fig. 213). Each sac is composed of a thin homogeneous membrane lined by cuboid epithelium. The interior of the sac in adult life contains a transparent, viscid, fluid containing albumin and termed "colloid" substance. Externally, the sacs are surrounded by a plexus of capillary blood-vessels and lymphatics. The individual sacs are united and supported by connective tissue, which forms, in addition, a covering for the entire gland.

Function of the Thyroid.—The knowledge at present possessed as to the function of the thyroid gland, especially in mammals, is the outcome of a study of the effects which follow its arrested development in the child, its degeneration in the adult, and its extirpation in the human being as well as in animals. The results, however, which follow its extirpation are not always uniform in all animals, though sufficient reasons for the lack of uniformity can not always be assigned.

Cretinism, a condition characterized by a want of physical and mental development, is associated with, if not directly dependent on, a congenital absence of the thyroid, or its arrested development during the early years of childhood.

Myxedema, a condition of the skin in which there is a hyperplasia of the connective tissue, of an embryonic type, rich in mucin, is generally regarded as one of the effects of degenerative processes in the thyroid. Partly in consequence of this change in the skin the face becomes broader, swollen, and flattened, giving rise to a loss of expression. At the same time the mind becomes dull, clouded, even approximating the idiotic type. This supposed infiltration of the skin with mucin was termed myxedema by Ord, who at the same time associated it with a change in the structure of the thyroid as a result of which it became functionally useless.

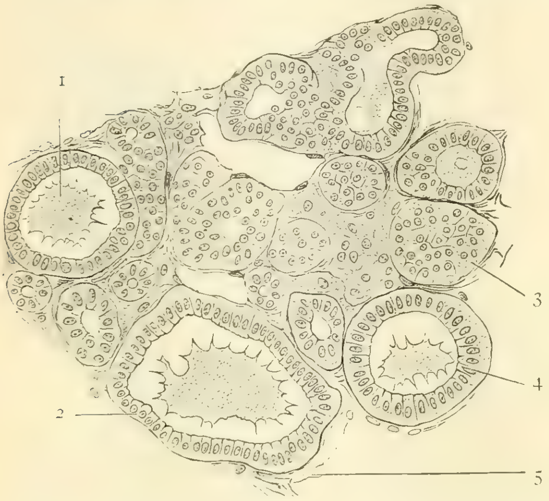


FIG 213.—A LOBULE FROM A THIN SECTION OF THE THYROID GLAND OF AN ADULT MAN. 1. Colloid substance. 2. Epithelium. 3. Tangential section of a tubule, the epithelium viewed from the surface. 4. Tubule in transverse section. 5. Connective tissue.—(*Stöhr.*)

Extirpation of the thyroid, for relief from symptoms due to grave pathologic changes, has been followed in human beings by symptoms similar to those of myxedema. To this condition the terms operative myxedema and cachexia strumipriva have been applied.

After the publication of the history of the myxedema which followed surgical removal of the thyroid, Schiff, in 1887, repeated his earlier experiments on dogs, and found again that removal of the thyroid was speedily followed by tremors, convulsions, and death. Similar experiments were made by Horsley on monkeys, with results which resembled those characteristic of myxedema. Among the symptoms which developed within a few days after the removal of the gland may be mentioned loss of appetite; fibrillar contractions of muscles; tremors and spasms; mucinoid degeneration of the skin, giving rise to puffiness of the eyelids and face and to a swollen condition of the abdomen; hebetude of mind, frequently terminating in idiocy; fall of blood-pressure; dyspnea; albuminuria; atrophy of the tissues, followed by death of the animal in the course of from five to eight weeks. The complexus of symptoms observed in monkeys was divided by Horsley into three stages: viz., the neurotic, the mucinoid, and the atrophic.

It is evident that the pressure of the thyroid is essential to the normal activity of the tissues generally. As to the manner in which it exerts its favorable influence, there is some difference of opinion. The view that the gland removes from the blood certain toxic bodies, rendering them innocuous and thus preserving the body from a species of auto-intoxication, is gradually yielding to the more probable view that the epithelium is engaged in the secretion of a specific material, which finds its way into the blood or lymph and in some unknown way influences favorably tissue metabolism. This view of the function of the thyroid is supported by the fact that successful grafting of a portion of the thyroid beneath the skin or in the abdominal cavity will prevent the usual symptoms which follow thyroidectomy. The same result is obtained by the intravenous injection of thyroid juice or by the administration of the raw gland. It was shown by Murray that myxedematous patients could be benefited, and even cured, by feeding them with fresh thyroids or with the dry extract.

The chemic features of the material secreted and obtained from the structures of the thyroid indicate that it is a complex proteid containing iodin, which, under the influence of various reagents, undergoes cleavage, giving rise to a non-proteid residue, which carries with it the iodin and phosphorus. The amount of iodin in the thyroid varies from 0.33 to 1 milligram for each gram of tissue. To this compound the term *thyroiodin* has been given. The administration of this compound produces effects similar to those which follow the therapeutic administration of the fresh thyroid itself; viz., a diminution of all myxedematous symptoms. In normal states of the body, thyroiodin influences very actively the general metabolism. It gives rise to a decomposition of fats and proteids and to a decline in body-weight. In large doses it may produce toxic symptoms, *e. g.*, increased cardiac action, vertigo, and glycosuria.

The conclusions as to the functions of the thyroid gland which have been drawn from the results that have followed its removal from animals by surgical procedures, have been made questionable, since the discovery of the parathyroid glands and a study of the phenomena which follow when they alone are removed. From their situation and close relationship to the thyroid gland it is generally accepted, that in the earlier experiments, especially those made on cats and dogs, and some other carnivorous animals, both sets of glands were removed and hence the symptoms which developed after the removal of the thyroids were due to the loss of function not only of the thyroid but of the parathyroids as well.

The Parathyroids.—The parathyroids are small bodies, usually four in number, two on each side. They are divided into superior and inferior. The superior are situated internally and on the posterior surface in close relation to, and frequently imbedded in, the substance of the thyroid; the inferior are situated externally, sometimes in contact with, and at other times removed a variable distance from the thyroid. Microscopically the parathyroids consist of thick cords of epithelial cells separated by septa of fine connective tissue and surrounded by capillary blood-vessels. Chemic analysis shows that they also contain iodin in combination with some organic compound.

Effects of Parathyroid Removal.—The surgical removal of the parathyroids is followed in the course of from two to five days by the death of the animal preceded in most instances by a series of symptoms which are embraced under the general term "tetany." These symptoms are fibrillary contractions of muscles, tremors, spasmodic contractions and paralyses of groups of muscles and not infrequently convulsive seizures and coma. During the convulsion there is an acceleration of the heart-beat, and increase in the respiratory movements which frequently become dyspneic in character. There is also a loss of appetite, nausea, mucous vomiting, and diarrhea. Death may occur during a convulsion or from coma. (Morat and Doyon.)

These results for the most part occur only when all the parathyroids are removed. It is asserted that even if one gland is retained the animal does not die. The above described symptoms may manifest themselves, however, but they are slight in degree.

Vincent and Jolly have recently published the results of a series of experiments which seem to negative to some extent the preceding statements. These experimenters state that while it is true, that, as a rule, the removal of both thyroids and parathyroids in the carnivora is a fatal operation, there are nevertheless many exceptions; and in the mammalia generally, *e.g.*, cats, dogs, foxes, guinea-pigs, rats and monkeys, the exception becomes the rule as more than 51 per cent. of animals survived the operation for a prolonged period and of these 68 per cent. showed no specific symptoms of any kind. From the contradictory observations it is evident that the subject needs further investigation.

The Pituitary Body.—This is a small body lodged in the sella turcica of the sphenoid bone. It consists of an anterior lobe, somewhat red in color, and a posterior lobe, yellowish-gray in color. (Fig. 214.) The former is much the larger and partly embraces the latter. The anterior lobe is developed from an invagination of the epiblast of the mouth cavity, and consists of distinct gland tissue. The posterior lobe is an outgrowth from the brain, and is connected with the infundibulum by a short stalk. It has been suggested that the term infundibular body be reserved for the posterior lobe, and the term hypophysis cerebri for the anterior lobe. This distinction appears to be desirable, inasmuch as in their origin and structure they are separate and distinct bodies.

Removal of the hypophysis cerebri, or the pituitary body, is always followed by a fatal result, preceded by symptoms not unlike those which follow removal of the thyroid: viz., anorexia, tremors, spasms, etc. Degeneration of the pituitary body has been found in connection with a hypertrophic condition of the bones of the face and extremities to which the term acromegalia has been given.

Intravenous injection of an extract of the pituitary increases the force of the heart-beat without any change in its frequency, and causes a rise of blood-pressure from a stimulation of the arterioles (Schäfer and Oliver). The material secreted by the pituitary has not been isolated, hence its chemic features are unknown. After its formation it probably passes through a system of ducts into the cerebrospinal fluid, after which it influences the metabolism of the nerve and osseous tissues as well as the force of the heart-muscle.

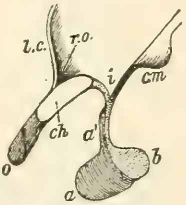


Fig. 214.—Sagittal Section of the Pituitary Body and Infundibulum with Adjoining Part of Third Ventricle. *a.* Anterior lobe. *a′.* A projection from it toward the front of the infundibulum. *b.* Posterior lobe connected by a stalk with the infundibulum. *i. l.c.* Lamina cinerea. *o.* Right optic nerve. *ch.* Section of optic chiasm. *r.o.* Recess of ventricle above the chiasma. *cm.* Corpus mammillare.—(*Schwalbe, from Quain.*)

An extract of the anterior lobe itself exerts no appreciable effect on the blood-pressure or on the rate of the heart-beat, nor does it influence the circulatory and respiratory organs. An extract of the infundibular body intravenously injected, however, gives rise to increased blood-pressure and to a slowing of the heart-beat (Howell).

Adrenal Bodies, or Suprarenal Capsules.—These are two flattened bodies, somewhat crescentic or triangular in shape, situated each upon the upper extremity of the corresponding kidney, and held in place by connective tissue. They measure about 40 mm. in height, 30 mm. in breadth, and from 6 to 8 mm. in thickness. The weight of each is about 4 gm.

Function of the Adrenal Bodies.—It was observed by Addison that a profound disturbance of the nutrition, characterized by a bronze-like discoloration of the skin and of the mucous membranes of the mouth, extreme muscular weakness, and profound anemia, was associated with, if not dependent on, pathologic conditions of the suprarenal glands. In the progress of the disease the asthenia gradually increases, the heart becomes weak, the pulse small, soft, and feeble, indicating a general loss of tone of the muscular and vascular apparatus. Death ensues from paralysis of the respiratory muscles. The essential nature of the lesion which gives rise to these symptoms has not been determined.

Removal of these bodies from various animals is invariably and in a short time followed by death, preceded by some of the symptoms characteristic of Addison's disease. Their development, however, is more acute. From the fact that animals so promptly die after extirpation of these bodies, and the further fact that the blood of such animals is toxic to the subjects of recent extirpation, but not to normal animals, the conclusion was drawn that the function of the adrenal bodies is to remove from the blood some toxic product of muscle metabolism. Its accumulation after extirpation gives rise to death through auto-intoxication.

On the supposition that the adrenals might secrete and pour into the blood a specific material which favorably influences general metabolism, Schäfer and Oliver injected hypodermically glycerin and water extracts, and observed at once an increased activity of the heart-beats and of the respiratory movements. The effects, however, were only transitory. When these extracts are injected into the veins directly, there follows in a short time a cessation of the auricular contraction of the heart, though the ventricular contraction continues with an independent rhythm. If the vagi are cut previous to the injection or if the inhibition is removed by atropin, the rapidity and vigor of both auricles and ventricles are increased. Whether the inhibitory influence is removed or not, there is a marked increase in the blood-pressure, though it is greater in the former instance. This is attributed to a direct stimulation and contraction of the muscle-fibers of the arterioles themselves, and not to vaso-motor influences, as it occurs also after division of the cord and destruction of the bulb. The contraction of the arterioles is quite general, as shown by plethysmographic studies of the limbs, spleen, kidney, etc. Applied locally to the mucous membranes, adrenal extract produces contraction of the blood-vessels and pallor. The skeletal muscles are affected by the extract very much as they are by veratrin. The duration of a single contraction is very much prolonged, especially in the phase of relaxation or of decreasing energy.

It is evident from these experiments that the adrenal bodies are engaged in elaborating and pouring into the blood a specific material which stimulates to increased activity the muscle-fibers of the heart and arteries, and thus assist in maintaining the normal blood-pressure as well as the tonicity of the skeletal muscles. An alkaloidal substance was isolated by Abel from extracts of this gland, to which the term *epinephrin* was given. A crystallizable substance was isolated first by Takamine and later by Aldrich, to which the term *adrenalin* was given. Both substances are apparently equally efficacious in causing contraction of the blood-vessels and in raising the blood-pressure. The question as to which of these two substances represents the active principle of the gland is as yet a subject of discussion.

The Spleen.—The spleen is a soft bluish-red organ, oval in shape, from twelve to fifteen centimeters long by eight broad and four thick. It is situated in the left hypochondrium between the stomach and the diaphragm. In this situation it is held in position by a fold of the peritoneum which passes from the upper border to the diaphragm.

Structure.—A section of the spleen shows that it consists of connective tissue, blood-vessels, lymph-corpuscles, and lymphoid tissue. The surface of the spleen is covered by a capsule composed of dense fibrous tissue, from the inner surface of which septa or trabeculæ pass inward toward the center of the organ. In their course they give off a series of processes which unite freely, forming a spongy connective-tissue framework. The capsule and the main trabeculæ in some animals contain numerous non-striated muscle-fibers. In man they are relatively few in number. The blood-vessels which enter the spleen are supported by the connective-tissue septa. As they pass toward the center of the organ they divide very rapidly and soon diminish in size. In their course small branches are given off, which penetrate the intertrabecular tissue and become encased with spheric or cylindric masses of adenoid tissue known as Malpighian corpuscles. These corpuscles are composed largely of leukocytes. In some animals the leukocytes, instead of being arranged in masses, are distributed along the walls of the artery as a continuous layer. Within the corpuscles the arteries pass into capillaries; whether the artery passes directly to the splenic pulp or indirectly by way of the corpuscles, its ultimate branches terminate in capillaries which open into the spaces of the splenic pulp. From these spaces a network of venules gathers the blood and transmits it to the veins. It is a disputed question as to whether the spaces are lined by epithelium, thus forming a continuous blood channel, or whether they are wanting in this histologic element.

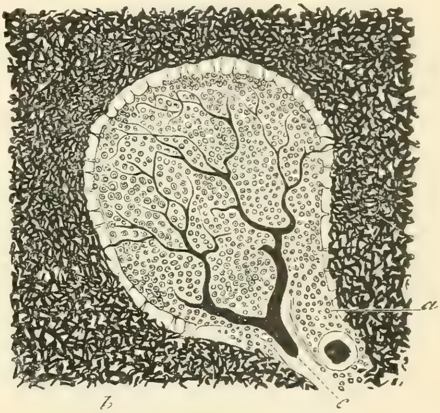


FIG. 215.—MALPIGHIAN CORPUSCLE OF A CAT'S SPLEEN INJECTED. *a.* Artery. *b.* Meshes of the pulp injected. *c.* The artery of the corpuscle ramifying in the lymphatic tissue composing it.

The Splenic Pulp.—The spaces of the connective-tissue framework are filled with a dark red semifluid mass known as the splenic pulp. When microscopically examined, the pulp presents a fine loose network of adenoid tissue, large numbers of leukocytes or lymph-corpuscles, red corpuscles in various stages of disintegration, and pigment granules. Chemic analysis reveals the presence of a number of nitrogen-holding bodies, *e. g.*, leucin, tyrosin, xanthin, uric acid; organic acids, *e. g.*, acetic, lactic, succinic acids; pigments containing iron, and inorganic salts.

The Functions of the Spleen.—Notwithstanding all the experiments which have been made to determine the functions of the spleen, it can not be said that any very definite results have been obtained. The fact that the spleen can be removed from the body of an animal without appreciably interfering with the normal metabolism would indicate that its function is not very important. The chief changes observed after such a procedure are an enlargement of the lymphatic glands and an increase in the activity of the red marrow of the bones. The presence of large numbers of leukocytes in the splenic pulp and in the blood of the splenic vein suggested the idea that the spleen is engaged in the production of leukocytes, and to this extent contributes to the formation of blood. The presence of disintegrated red blood-corpuscles has suggested the view that the spleen exerts a destructive action on functionally useless red corpuscles. These and other theories as to splenic functions have been offered by different observers, but all are lacking positive confirmation.

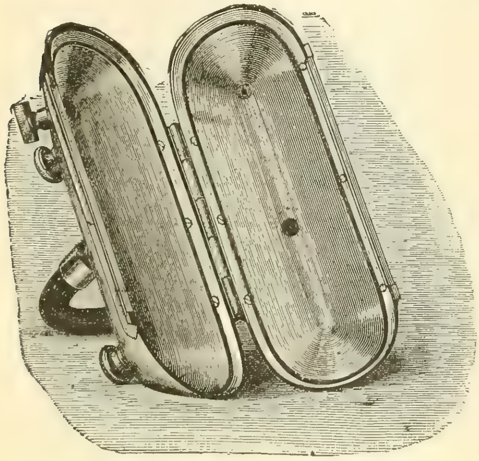


Fig. 216.—Spleen Oncometer Laid Open.

Volume Variations of the Spleen.—It was shown some years since by Roy, with the aid of the plethysmograph, that the spleen undergoes rhythmic variations in volume from moment to moment. In the cat and in the dog the diminution in the volume (the systole) and the increase in volume (the diastole) together occupied about one minute.

This fact was determined by withdrawing the spleen through an opening in the abdominal wall and enclosing it in a box with rigid walls, the interior of which was connected with a piston recording apparatus. The system being filled with oil, each variation in volume was attended by a to-and-fro displacement and a corresponding movement of the recording lever. The special form of plethysmograph used for this purpose is known as the oncometer or bulk measurer, and the recording apparatus as the oncograph (Fig. 216 and Fig. 222).

The cause of these variations in volume Roy attributed to a rhythmic contractility of the non-striated muscle-fibers in the capsule and trabeculæ, and not to changes in the arterial blood-pressure, as the curve of the pressure taken simultaneously remained practically uniform. The effect of the rhythmic contractions of the splenic muscle tissue is to force the blood through the organ, a condition necessitated perhaps by the pressure relations within, though what function is thereby fulfilled is not apparent.

It was subsequently shown by Schäfer and Moore that the splenic volume is extremely responsive to all fluctuations of the arterial blood-pressure; that though the spleen may passively expand and recoil in response to the rise and fall of the blood-pressure, nevertheless the reverse conditions may obtain: viz., that the splenic volume may diminish as the pressure rises, if the splenic arterioles contract simultaneously with the contraction of the arterioles generally. On the contrary, the splenic volume may increase coincident with a dilatation of the splenic and systemic arterioles. In addition to the rhythmic variations, the spleen steadily increases in volume for a period of five hours after digestion, and then gradually returns to its former condition.

Influence of the Nerve System.—The nerves which supply the vascular and visceral muscles in the spleen are derived directly from the semilunar ganglion (post-ganglionic fibers) and pass to it in company with the splenic artery. The nerve-cells from which they arise are in physiologic relation with nerve-fibers (pre-ganglionic fibers) which emerge from the spinal cord in the anterior roots of the third thoracic to the first lumbar nerves inclusive, though they are found most abundantly in the sixth, seventh, and eighth thoracic nerves. Their center of origin is in the medulla oblongata.

Stimulation of the nerves in any part of their course gives rise to a diminution in splenic volume; division of the nerves is followed by an increase in the volume. In asphyxia the spleen is small and contracted, a condition attributed to a stimulation of the centers in the medulla by the venosity of the blood.

The musculature of the spleen may also be excited to contraction by reflex influences, as shown by the fact that stimulation of the central end of a sensory nerve is attended by a diminution of volume.

Inasmuch as the excised spleen will continue to exhibit variations in volume when perfused with blood, it would appear that it possess some mechanism independent to some extent of the nerve system.

CHAPTER XVIII.

EXCRETION.

As stated in the preceding chapter, the term excretion is limited to the process by which the end-products of tissue metabolism are removed from the body, the nature of the process, however, differing in no essential particulars from that underlying the process of secretion. The histologic structures involved and the forces at work being of the same general character, it is impossible to draw any sharp line of distinction between them. As a general fact it may be stated that in their composition all the characteristic ingredients of the excretions are incapable either of entering into the formation of tissue or of undergoing oxidation for the purpose of heat-production. As the retention of these end-products in the body would exert a deleterious influence on normal metabolism, their prompt removal becomes essential to the maintenance of physiologic activity. The principal excretions of the body—urine, perspiration, and bile—are complex fluids in which, with the exception of those given off in the lungs, are to be found in varying proportions the chief end-products of metabolism.

THE URINE.

Normal urine has a pale yellow or amber color, an aromatic odor, an acid reaction, and a specific gravity of 1.020. As a rule, it is perfectly transparent, though its transparency may be diminished from the presence of mucus, calcium and magnesium phosphates, and mixed urates.

The *color*, which varies within physiologic limits from a pale yellow to a reddish-brown, is due to the presence of the coloring-matters *urobilin*, *urochrome*, and *uroerythrin*, all of which are derivatives from the bile pigments absorbed from the liver or the alimentary canal.

The *reaction* of the urine is acid, owing to the presence of the acid phosphates of sodium and calcium. The degree of acidity, however, varies at different periods of the day. Urine passed in the morning is strongly acid, while that passed during and after digestion, especially if the food be largely vegetable in character and rich in alkaline salts, is either neutral or alkaline in reaction. The diminished acidity after meals is attributed to the formation of hydrochloric acid by the gastric glands and the consequent liberation of bases which are excreted in the urine. The phosphoric acid which enters into combination with sodium and potassium bases is a product of tissue metabolism.

The *specific gravity* is about 1.020, though it varies from 1.015 to 1.025. It will diminish, other things being equal, with increased consumption of water and diminished activity of the skin; it will be increased of course by the opposite conditions.

The *quantity* of urine excreted in twenty-four hours varies from 1200 to 1700 c.c. Amounts both above and below these are frequently passed from a variety of causes.

The *odor* of the urine is characteristic and due to the presence of aromatic compounds.

COMPOSITION OF URINE.

Water,	1500.00	c.c.
Total solids,	72.00	grams.
Urea,	33.18	“
Uric acid (urates),	0.55	“
Hippuric acid (hippurates),	0.40	“
Kreatinin, xanthin, hypoxanthin, guanin, ammonium salts, pigment, etc.	11.21	“
Inorganic salts: sodium and potassium sulphates, phosphates, and chlorids; magnesium and calcium phosphates,	27.00	“
Organic salts: lactates, acetates, formates in small amounts,		
Sugar,	a trace	
Gases, nitrogen, and carbonic acid.		

The estimation of total urinary solids in any given sample of urine is frequently a matter of clinical interest. This may approximately be attained by multiplying the last two figures of the specific gravity by the coefficient of Haeser or Christison, 2.33. The result expresses the total solids in 1000 parts: *e. g.*, urine with a specific gravity of 1.020 would contain 20 × 2.33, or 46.60 grams of solid matter per 1000 c.c. If the amount passed in twenty-four hours be 1500 c.c., the total solids would amount to 69.9 grams.

The Water of the Urine.—The amount of urinary water and its ratio to the solid constituents will vary with the amount consumed and the activity of the skin and lungs. In summer the foods, liquid and solid, remaining the same, the quantity of water in the urine is diminished in consequence of increased activity of skin and lungs and the ratio of water to solids decreased. In winter the reverse conditions obtain. The food remaining the same, the consumption of large quantities of water hastens at least the removal of end-products from the tissues and thus increases the urinary solids.

Urea is the most abundant of the organic constituents of the urine and is present to the extent of from 2 to 3 per cent. It is a colorless neutral substance, crystallizing under varying conditions in long silky needles or in rhombic prisms. It is soluble in water and alcohol. It is composed of CON_2H_4. When subjected to prolonged boiling, it combines with water, giving rise to ammonium carbonate. The presence of *Micrococcus ureæ* in urine will also convert the urea, by combining it with two molecules of water, into ammonium carbonate, $CON_2H_4 + 2H_2O = (NH_4)_2CO_3$.

The average amount of urea excreted daily varies from 30 to 34 grams. As urea is now known to be the principal end-product of proteid metabolism within the body, it is evident that the quantity produced and eliminated in the twenty-four hours will depend on the quantity of proteid food consumed and on the extent to which the proteid constituents of the tissues are metabolized. In the condition of nutritive equilibrium, when the proteid ingested is 100 grams and the urea egested 31.5 grams, it is difficult to state the percentage of urea which is derived from the metabolism of the proteid food (circulating proteid) and that derived from the metabolism of the proteids of the tissues (organ proteid). In this condition, however, it is found that if the proteid consumed is varied within limits above or below the standard amount of 100 grams, the quantity of urea excreted rises and falls in practically the same ratio, indicating apparently that the production of urea is directly dependent on the proteid supply. On the contrary, it has been observed in human beings in the fasting condition that for a period of ten days there is a daily excretion of about 21 grams of urea, equivalent to about 70 grams of proteid. Again, contrary to former views, the metabolism of proteid and the production of urea are practically independent of muscular work. Even after severe labor extending over a period of some hours there is no noticeable increase in the urea eliminated.

Seat of Urea Formation.—It is quite certain in the light of present knowledge that urea is partly formed in the liver by the action of the cells out of cleavage products of proteid metabolism. The particular compounds out of which the cells synthetize urea are the ammonium salts, especially the carbamate and carbonate. The experimental reasons for this view have already been stated on page 462.

Uric acid is one of the constant ingredients of the urine. It is a crystalline nitrogen-holding body closely resembling urea, its formula being $C_5H_4N_4O_3$. The total quantity excreted daily varies from 0.2 to 1 gram. It is doubtful if uric acid exists in a free state in the urine, the indications being that it is combined with sodium and potassium in the form of a quadriurate. The urates are frequently deposited when in excess from the urine as a brick-red sediment, the color being due to their combination with the coloring-matter uroerythrin. When pure, uric acid crystallizes in the rhombic form, though it assumes a variety of forms. Uric acid was long regarded as a product of general proteid metabolism and for chemic reasons an antecedent of urea. This view has been abandoned. At present it is believed that it is a cleavage product of nuclein, a constituent of all cell nuclei. In the metabolism of nuclein a proteid and nucleic acid are formed, from the latter of which uric acid is derived. Nucleic acid when decomposed yields a series of bases, such as xanthin, hypoxanthin, adenin, guanin, etc. Because of the fact that these bodies can also be obtained from a synthetized body termed *purin* they are known collectively as the purin bases. Though there is a close relationship between uric acid and the purin bases, it has been impossible to experimentally derive one from the other. When hypoxanthin, however, is given internally it is oxidized and converted into uric acid. It is extremely probable, therefore, that uric acid is an oxidation product of one or more of the purin bases.

It is probable, however, that not all of the uric acid eliminated is derived from the nuclein of tissue-cells and their decomposition products, the purin bases. Some of it is undoubtedly derived from the nucleins contained in foods. The uric acid eliminated is therefore partly endogenous and partly exogenous in origin.

Xanthin, hypoxanthin, guanin, etc., are also found in urine in small but variable amounts. They are nitrogenized compounds derived mainly from the metabolism of the nuclein bodies.

Kreatinin is a crystalline nitrogenous compound closely resembling kreatin, one of the constituents of muscular tissue. The amount excreted daily is about 1 gram. Though kreatinin may arise in consequence of proteid metabolism, it is probable that it is largely derived from a transformation of the kreatin contained in the meat consumed as food.

Hippuric acid in combination with sodium and potassium is very generally present in urine, though in small amounts. It is more abundant in the urine of the herbivora than the carnivora. In man the amount excreted daily is about 0.7 gram, though the amount may be raised by a diet of asparagus, plums, cranberries, etc., and by the administration of benzoic and cinnamic acids. There is evidence that hippuric acid is formed in the kidney from benzoic acid, its precursors, or related bodies. Various compounds of this class are found in vegetable foods, a fact which may account for the increase in the excretion of hippuric acid on a vegetable diet.

Leucin, tyrosin, phenol, cystin, indoxyl, skatoxyl, are found in small amounts even under normal conditions. They arise from putrefactive change in the intestine.

Inorganic Salts.—Sodium and potassium phosphates, known as the *alkaline phosphates*, are found in both blood and urine. The total quantity excreted daily is about 4 grams. Calcium and magnesium phosphates, known as the *earthy phosphates*, are present to the extent of 1 gram. Though insoluble in water, they are held in solution in the urine by its acid constituents. If the urine be rendered alkaline, they are at once precipitated. Sodium and potassium sulphates are also present to the extent of about 2 grams. The phosphoric and sulphuric acids which are combined with these bases enter the body for the most part in the foods, though there is evidence that they also arise by oxidation in consequence of the metabolism of proteids which contain phosphorus and sulphur. Sodium chlorid is the most abundant of the inorganic salts. It is derived mainly from the food. The amount excreted is about 15 grams in twenty-four hours.

THE KIDNEYS.

The **kidneys** are the organs engaged in the excretion of the urinary constituents from the blood. They resemble a bean in shape, are from 10 to 12 centimeters in length, 2 in breadth, and weigh from 144 to 170 grams. They are situated in the lumbar region, one on each side of the vertebral column behind the peritoneum, and extend from the eleventh rib to the crest of the ilium. The anterior surface is convex, the posterior surface concave. The latter presents a deep notch—the hilum. The kidney is surrounded by a thin smooth membrane composed of white fibrous and yellow elastic tissue; though it is attached to the surface of the kidney by minute processes of connective tissue, it can very readily be torn away. The substance of the kidney is dense but friable.

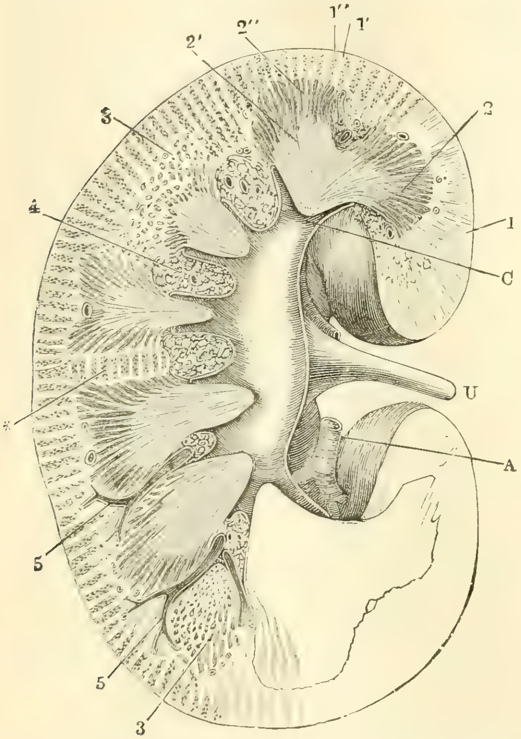


Fig. 217.—Longitudinal Section through the Kidney, the Pelvis of the Kidney, and a Number of Renal Calyces. A. Branch of the renal artery. U. Ureter. C. Renal calyx. 1. Cortex. 1'. Medullary rays. 1''. Labyrinth, or cortex proper. 2. Medulla. 2'. Papillary portion of medulla, or medulla proper. 2''. Border layer of the medulla. 3, 3. Transverse section through the axes of the tubules of the border layer. 4. Fat of the renal sinus. 5, 5. Arterial branches. *. Transversely coursing medulla rays.—(*Tyson, after Henle.*)

Upon making a longitudinal section of the kidney it will be observed that the hilum extends into the interior of the organ and expands to form a cavity known as the sinus, in which are found the blood-vessels, nerves, and duct (Fig. 217). This cavity is mainly occupied by the upper part of the renal duct, the ureter, the interior of which is termed the pelvis. The ureter divides into several portions which terminate in small caps of calyces which receive the apices of the pyramids. The **parenchyma** of the kidney consists of two portions: viz.—

1. *An internal* or *medullary portion*, consisting of a series of pyramids or cones, some twelve or fifteen in number, which present a distinctly striated appearance.
2. *An external* or *cortical portion*, half an inch in thickness and distinctly friable in character.

The Histology of the Kidney.—The kidney is composed of a connective-tissue framework supporting secreting tubules, blood-vessels, lymphatics, and nerves, all of which are directly connected with the removal of the urinary constituents from the blood. The kidney is structurally a compound tubular gland. If the apex of each pyramid be examined with a lens, it will present a number of small orifices which may be regarded as the beginnings of the uriniferous tubules. From this point the tubules pass outward in a straight but somewhat diverging manner toward the cortex, giving off at acute angles a number of branches (Fig. 218). From the apex to the base of the pyramids they are known as the tubules of Bellini. In the cortical portion of the kidney the tubule becomes enlarged and twisted, and, after pursuing an extremely convoluted course, turns backward into the medullary portion for some distance, forming the ascending limb of Henle's loop; it then turns upon itself, forming the descending limb of the loop, reenters the cortex, again expands and becomes convoluted, and finally terminates in an ovoid enlargement known as Müller's or Bowman's capsule, in which is contained a small tuft of blood-vessels—the *glomerulus*. Each tubule consists of a basement membrane lined throughout its entire extent by epithelial cells. The epithelium as well as the tubule vary in shape and size in different parts of its course. In the capsule the epithelium is flattened, lining not only the inner surface of the capsule but reflected over the blood-vessels as well. This is known as the glomerular epithelium. In the convoluted portions of the tubules the epithelium is cuboidal, granular, and somewhat striated; in Henle's loop it is more or less flattened.

The Blood-vessels of the Kidney.—The renal artery enters the kidney at the hilum behind the ureter; it soon divides into several large branches which penetrate the substance of the kidney between the pyramids and pass outward into the cortex. At the base of the pyramids branches of the arteries form an anastomosing plexus. From this plexus vessels are given off, some of which follow the straight tubules toward the apex of the pyramids, vasa recta, while others enter the cortex and pass to its surface (Fig. 218). In the course of the latter small branches are given off, each of which soon divides and subdivides to form a ball of capillary vessels known as the *glomerulus*. These capillaries, however, do not anastomose, but soon reunite to form an efferent vessel the caliber of which is less than that of the afferent artery. In consequence of this, there is a greater resistance to the outflow of blood than to the inflow, and therefore a higher blood-pressure in the glomerulus than in capillaries generally. The relation of the glomerulus to the tubule is important from a

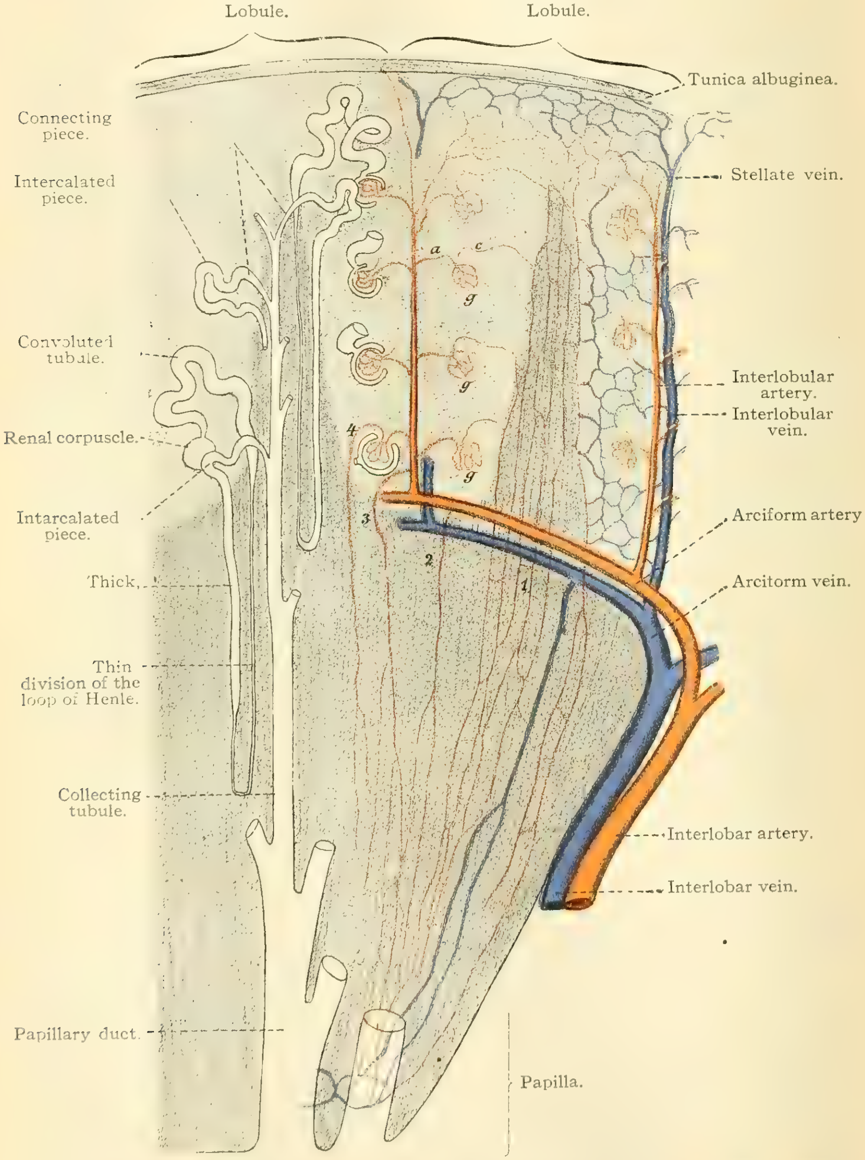

Lobule.
Lobule.
Tunica albuginea.
Connecting piece.
Intercalated piece.
Stellate vein.
a
c
g
Convoluted tubule.
g
Interlobular artery.
Interlobular vein.
4
Renal corpuscle.
g
Intarcalated piece.
3
Arciform artery
2
1
Thick,
Arciform vein.
Thin division of the loop of Henle.
Collecting tubule.
Interlobar artery.
Interlobar vein.
Papillary duct.
Papilla.

FIG. 218. SCHEME OF THE COURSE OF THE URINIFEROUS TUBULES AND THE RENAL VESSELS.

physiologic point of view. As stated above, the glomerulus is received into and surrounded by the terminal expansion or capsule of the tubule. This capsule, formed by an indentation of the terminal portion of the tubule, consists of two walls, an outer one consisting of an extremely thin basement membrane, covered by flattened epithelial cells, and an inner one consisting apparently only of flattened epithelium which is reflected over and closely invests the glomerular blood-vessels (Fig. 219). The blood is thus separated from the interior of the capsule by the epithelial wall of the capillary and the epithelium of the reflected wall of the capsule. During the periods of secretory activity the blood-vessels of the glomerulus are filled with blood to such an extent that the sac cavity is almost obliterated. After its exit from the capsule the efferent vessel of the glomerulus soon again divides and subdivides to form an elaborate capillary plexus which surrounds and closely invests the convoluted tubules. From this plexus as well as from the plexus which surrounds the straight tubules veins arise which pass toward and empty into veins at the base of the pyramids. The renal vein formed by the union of these latter veins emerges from the kidney at the hilum and finally empties into the vena cava inferior.

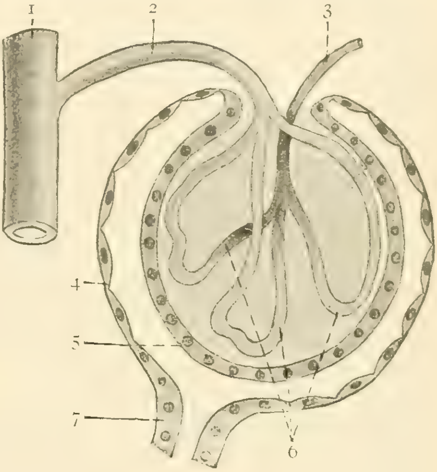


Fig. 219.—Scheme of the Renal or Malpighian Corpuscle. 1. Interlobular artery. 2. Afferent vessel. 3. Efferent vessel. 4. Outer wall. 5. Inner wall. 6. Glomerulus. 7. Neck of tubule.—(*Stöhr.*)

The **nerves** of the kidney are derived from the renal plexus and follow the course of the blood-vessels to their termination.

The Renal Duct.—The excretory duct of the kidney, the ureter, is a musculo-membranous tube about 5 mm. in diameter when distended, 30 cm. in length, and extends from the hilum to the base of the bladder. The upper extremity is expanded and within the renal sinus becomes irregularly branched, giving rise to a number of short tubes, called calyces, each of which embraces the apex of a Malpighian pyramid. The interior of the expanded portion of the ureter is known as the *pelvis.* The wall of the ureter consists of a mucous membrane, a muscle coat, and an external fibrous investment.

MECHANISM OF URINE SECRETION.

The secretion of urine is a complex process and susceptible of several interpretations. It was originally inferred by Bowman that, as the kidney presents anatomically an apparatus for filtration, the capsule with its enclosed glomerulus, and an apparatus for secretion, the epithelium of the urinary tubules, the elimination of the urinary constituents from the blood is accomplished by the two processes of filtration and secretion; that the water and highly diffusible inorganic salts simply pass by diffusion, under pressure, though the walls of the glomerular capillaries, while the organic constituents are removed by the epithelium lining the tubules.

Influenced largely by the facts of blood-pressure Ludwig advanced the view that the factors concerned in the secretion of urine were purely physical; that in consequence of the high pressure in the vessels of the glomeruli, due to the resistance offered by the smaller efferent vessel, all the urinary constituents were filtered off in a state of extreme dilution. In order to account for the higher percentage of the organic constituents in the urine, it was assumed that as the dilute urine passed through the tubules the water was partly reabsorbed, passing by diffusion into the lymph and blood until the urine acquired its normal characteristics. In support of this view, a large number of facts relating to the influence of an increase and a decrease of pressure in the blood-vessels of the glomeruli, the velocity of the blood-stream, etc., in determining the rate of urinary flow were adduced, all of which apparently indicated that the former stood to the latter in the relation of cause and effect, and that the formation of urine was accomplished entirely by physical forces.

The progress of physiologic investigation, however, has thrown some doubt on the validity of this physical interpretation, and has rather served to support the view of Bowman that the organic constituents at least are removed from the blood by a process of selection on the part of the epithelium of the convoluted part of the urinary tubules; in other words, that the secretion of urine is physiologic rather than physical. Heidenhain has brought forward a series of facts which support this view. As evidence that the cells possess a selective power, he presents the following experiment: The spinal cord of an animal is divided in the neck for the purpose of lowering the blood-pressure in the kidney below the pressure at which the urine is secreted; a solution of indigo-carmine is injected into the blood-vessels; after the lapse of ten minutes the animal is killed, the blood-vessels washed out with alcohol for the purpose of precipitating the indigo-carmine *in situ*. Section of the kidney shows a uniform blue stain of the cortex alone. Microscopic examination reveals the fact that the blue stain is due to the deposition of the pigment in the lumen and in the lumen border of the cells of the convoluted tubules and the ascending limb of Henle's loop; while the epithelium of Bowman's capsule as well as the glomerular epithelium present no evidence of pigmentation.

Nussbaum attempted to establish the secretory power of the epithelium in another way. In the frog the kidney receives blood from two sources: the glomeruli receive their blood from the renal artery, the tubules from the capillaries formed by the anastomosis of branches of the efferent vessel of the glomerulus and the branches of the renal portal vein. Nussbaum believed that by ligating the renal artery all glomerular activity could be abolished and the part played by the epithelium could be established. After so doing the flow of urine was at once checked; the injection of urea at once reestablished it. This fact was taken as a proof that the tubular epithelium not only excreted urea, but water and perhaps other constituents as well. It was also found that sugar, peptones, carmine, etc., which are always eliminated from the blood under normal conditions, are not removed after ligation of the renal artery. It was concluded from these experiments that the secreting structures of the kidney consist of two distinct systems, the glomerular and the tubular; the former secreting water, salts, sugar, peptone, etc.; the latter urea, uric acid, etc. These and similar facts indicate that the renal epithelium possesses a secretory rather than an absorptive function. Heidenhain and those who agree with him assert that even the water and inorganic salts which pass through the glomerular epithelium do so in consequence of cell selection and cell activity; that the entire process is one of secretion, though conditioned by blood-pressure, blood velocity, etc.

Influence of Blood-pressure.—Whether the elimination of the urinary constituents is entirely secretory (physiologic) in character or not there can be no doubt that the whole process is largely determined by the pressure and velocity of the blood in the glomerular capillaries, or, to state it more accurately, on the difference of pressure between the blood in the capillaries and the urine in the capsules. As a rule, this latter pressure is at a minimum. If the urine should accumulate in the ureter and tubules either from ligation or mechanical obstruction until its pressure approximates that of the blood, the secretion would be diminished if not abolished. It is difficult to determine the average pressure or velocity of the blood in the glomers ular capillaries, though they both must be greater than in capillarie- in other parts of the body, from the fact that the efferent vessel is narrower than the afferent, and therefore offers great resistance to the outflow of blood, a condition most favorable to the production of a high pressure in the glomerulus.

The pressure of the blood in the glomeruli may be raised and the velocity increased:

1. By an increase in blood-pressure generally.
2. By an increase in the pressure of the renal artery alone.

The first condition may be brought about by an increase in either the force or frequency of the heart's action or by a contraction of the arterioles of vascular areas in any or all parts of the body, excepting, of course, the renal vascular area. The second condition is brought about by a dilatation of the renal artery alone and possibly by a contraction of the efferent vessels of the glomeruli.

The pressure of the blood in the glomeruli may be diminished and the velocity decreased:

1. By a decrease in the blood-pressure generally.
2. By a decrease in the pressure of the renal artery alone.

The first condition is brought about by a decrease in either the force or frequency of the heart's action or by a dilatation of the arterioles of large vascular areas in any or all parts of the body. The second condition is brought about by contraction of the renal artery alone and possibly by a dilatation of the efferent vessels of the glomeruli. The effect of the contraction and relaxation of either the afferent or efferent vessels on the pressure within the glomerulus is shown in Figure 220.

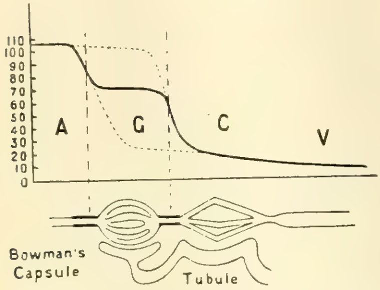
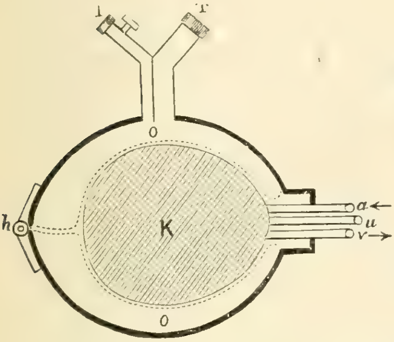


FIG. 220.—TO ILLUSTRATE THE EFFECT OF ACTIVE CHANGES IN THE VASA AFFERENTIA AND EFFERENTIA ON THE PRESSURE IN THE GLOMERULAR CAPILLARIES. A. Renal arteries. G. Glomerular capillaries. C. Tubular capillaries. V. Vein. The short thick lines represent the vasa afferentia and efferentia. The continuous heavy line represents the mean average pressure. If the vas afferens dilates and the vas efferens contracts separately or conjointly, the pressure will rise, as indicated by the upper dotted line. If the vas afferens contracts and the vas efferens dilates separately or conjointly, the pressure will fall, as indicated by the lower dotted line.—(*After Morat.*)

Coincident with the rise and fall of pressure in the glomerular capillaries there is a rise and fall in the rate of urinary flow. Thus it has been found that an increase in the aortic pressure from 127 to 142 mm. of mercury, by ligation of the carotid, femoral, and vertebral arteries, increased the rate of urinary flow from 8.7 grams in thirty minutes to 21.2 grams. On the contrary, a decrease in aortic pressure below 40 mm. of mercury caused by division of the spinal cord is followed by a total abolition of the urinary flow. These facts serve to indicate the dependence of the secretion on blood-pressure.

That there is an increase in the volume of the blood flowing through the kidney during its functional activity is apparent from inspection. It is enlarged, swollen, and red in color. The blood in the renal vein is bright red in color and contains more oxygen and less carbon dioxid than venous blood generally. During the intervals of activity the kidney diminishes in size, is pale in color and the blood of the renal vein dark and venous in character. These variations in the volume of the kidney have also been experimentally determined and registered by means of the oncometer and oncograph devised by Roy.

The oncometer consists of a metallic box (Fig. 221) composed of halves which open and close by means of a hinge. It is connected with a recording apparatus, the oncograph (Fig. 222), through the tube T. The kidney, withdrawn from the body, is placed within the oncometer. Through an opening in the side pass the artery, vein, and ureter. Between the kidney and the wall of the capsule there is placed a thin membrane. Oil is then poured through the side tube I until the space between the capsule and the kidney, as well as the tube leading to the chamber of the oncograph, are completely filled. When the tube I is closed, the conditions are such that all variations in the volume of the kidney are taken up and reproduced by the recording lever attached to the piston of the oncograph. A curve of the variations in the volume of the kidney is shown in Figure 223 taken simultaneously with the curve of the blood-pressure. An examination of this curve shows that the volume-changes coincide with changes in the blood-pressure, exhibiting not only the respiratory but also the cardiac undulations.



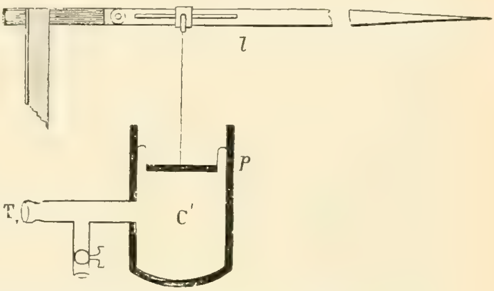


FIG. 221.—ONCOMETER. K. Kidney; the thick line is the metallic capsule. *h*. Hinge. I. Tube for filling apparatus. T. Tube to connect with T,, *a*, *v*, *u*. Artery, vein, ureter.—(*Stirling, after Roy.*)

FIG. 222.—ONCOGRAPH. C'. Chamber filled with oil, communicating by T, with T. *p*. Piston. *l*. Writing-lever.—(*Stirling, after Roy.*)

Influence of the Nerve System.—The influence of the nerve system in regulating the blood-supply to the kidney is evident from the results of experimentation. If the nerves which accompany the renal artery into the kidney are divided, the artery at once dilates, the kidney enlarges, and a copious flow of urine takes place. If the peripheral ends of these nerves be stimulated with the induced electric

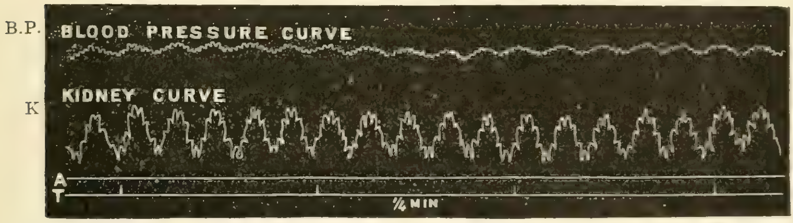


FIG. 223.—B. P. Blood-pressure curve. K. Curve of the volume of the kidney. T. Time curve; intervals indicate a quarter of a minute. A. Abscissa.—(*Stirling, after Roy.*)

current, the artery contracts, the kidney diminishes in size, and the flow of urine ceases. In addition to these vaso-constrictor nerves, there is evidence that the kidney also receives vaso-dilator nerves which emerge from the spinal cord and are found in the anterior roots of the eleventh, twelfth, and thirteenth dorsal nerves, in the dog. Direct and reflex stimulation of these nerves gives rise to a dilatation of the artery, a swelling of the kidney, and an increase in secretion, independent of any variation in general blood pressure.

The route of the vaso-constrictor nerves is, in the dog at least, through the splanchnics. Section of these nerves is followed by a dilatation of the renal vessels and an increase in the flow of urine. Stimulation of the peripheral ends is followed by a constriction of the vessels and a cessation of the flow of urine.

The vaso-motor center for the blood-vessels of the kidney is in all probability situated in the medulla oblongata in close proximity to the general vaso-motor centers, though subordinate centers are doubtless present in the spinal cord. It was found by Bernard that puncture of the medulla was occasionally followed by a profuse secretion of urine without the presence of sugar. The route of the vaso-motor impulses which influence the renal blood-supply is down the cord through the splanchnics and through the renal plexus.

Influence of Variations in the Composition of the Blood.—As it is the function of the kidneys to excrete water, inorganic salts, and various end-products from the blood and thus maintain a general average composition, it is highly probable that as soon as they accumulate beyond a certain percentage they themselves act as stimulants to renal activity, either by acting directly on the renal epithelium or by increasing the glomerular pressure. There is evidence at least that urea acts in the former manner. An excess of water in the blood, that from copious drinking or from a sudden checking of the skin from a fall of temperature, will act in the latter way. The introduction into the blood of inorganic salts, such as potassium nitrate, sodium acetate, etc., will in a short time lead to increased activity of the kidneys, as shown by an increase in the quantity of urine excreted. The manner in which these agents and other members of their class, the so-called saline diuretics, increase renal activity is yet a subject of discussion. On the one hand, it is stated that they promote an absorption of water from the tissues to such an extent that a condition of hydremic plethora is produced, which in itself increases not only the general blood-pressure but the local renal pressure as well, and that it is this factor which is the cause of the increased flow of urine. On the other hand, it is asserted that though the salts increase the local pressure and the volume of the kidney, they nevertheless act specifically on the renal epithelium, and therefore may be regarded as secreto-motor agents. An increase in the percentage of sugar or urea in the blood has a similar influence on the kidney.

The Storage and Discharge of Urine.—Urination.—The urinary constituents, as soon as they are eliminated from the blood, pass into and through the uriniferous tubules and by them are discharged into the pelvis of the kidney. They then enter the ureter by which they are conducted to the bladder. The immediate cause of this movement is undoubtedly a difference of pressure between the terminal portions of the tubules and the terminal portion of the ureter, aided by the peristaltic contraction of the muscle wall of the ureter.

The *bladder* is a reservoir for the temporary reception of the urine prior to its expulsion from the body. When distended it is ovoid in shape and is capable of holding from 600 to 800 cu. cm. The bladder is composed of four coats: viz., serous, muscle, areolar, and mucous. The muscle coat consists of external longitudinal and internal circular and oblique layers of fibers of the non-striated variety which collectively encircle the entire organ. As these fibers by their contraction expel the urine from the bladder, they are known collectively as the *detrusor urinæ* muscle. At the exit of the bladder the circular fibers are somewhat increased in number, giving rise to the appearance of a distinct muscle which has been termed the *sphincter vesicæ* muscle. The presence of this muscle has, however, been denied and the retention of the urine has been attributed to mechanic conditions at the neck of the bladder. The urethra just beyond the bladder is provided with a distinct circular muscle composed of striated fibers, the *sphincter urethræ* muscle. When the urine passes into the bladder it is retained there and prevented from escaping by the contraction of this latter muscle. Under normal conditions the urine accumulates to a considerable extent before the intra-vesic pressure gives rise to a characteristic sensation and the desire for urination.

The Nerve Mechanism of Urination.—The muscle mechanisms which retain as well as expel the urine are under the control of the nerve system. The sphincter urethræ muscle, which by the orifice of the bladder is closed, is kept in a state of tonic contraction by nerve impulses coming from the spinal cord through the anterior roots of the third and fourth sacral nerves. The detrusor urinæ muscle is excited to contraction by impulses coming likewise through the sacral nerves and through the upper lumbar nerves from the cord. The centers of origin for these two sets of motor nerves are located in the cord in the neighborhood of the fifth lumbar vertebra. The expulsion of the urine is largely a reflex act, though under the control of the will. When the desire to urinate is experienced, nerve impulses are coming through sensory nerves from the mucous membrane of the bladder which are reflected to the centers governing the sphincter urethræ and detrusor urinæ muscles and to the brain. The effect of the reflected impulses is to inhibit the sphincter center and to stimulate the detrusor center. If the act of urination is to be permitted, volitional impulses descend through the spinal cord which have the effect of still further inhibiting the sphincter center and stimulating the detrusor center, the result being a relaxation of the sphincter muscle and a contraction of the detrusor muscle and the expulsion of the urine. If the act of urination is to be suppressed, volitional impulses inhibit the detrusor center and stimulate the sphincter.

PERSPIRATION; SEBUM.

The perspiration or sweat, the chief secretion of the skin, is a clear colorless fluid, slightly acid in reaction and saline to the taste. Its specific gravity varies from 1.003 to 1.006. Unless collected from the soles of the feet and the palms of the hand, it is apt to be mixed with epithelial cells and sebum. The total quantity of perspiration secreted daily has been variously estimated at from 700 to 1000 grams; the exact amount, however, is difficult of determination, for the reason that the rate of secretion varies readily with variations in temperature, food, drink, season of the year, etc.

Chemic analysis of the sweat shows that it contains but from 0.5 to 2.5 per cent. of solid constituents, the variation in the percentage depending on the quantity of water secreted. The solids consist of traces of urea, neutral fats, lactic and sudoric acids in combination with alkaline bases, and inorganic salts (Fovel). Other observers, however, have not been able to detect the presence of either lactic or sudoric acid. Urea is a constant ingredient, though its percentage is extremely small, possibly not more than 0.1 per cent. The amount, however, may be very much increased in uremic conditions, the result of acute or chronic disease of the kidneys. The inorganic constituents consist mainly of sodium chlorid and alkaline and earthy phosphates. Carbonic acid is also present in the free state as well as in combination with alkaline bases.

The very small quantity of the solid constituents in the sweat, taken in connection with the fact that it is excreted most abundantly when the external temperature is high, indicates that it is not so important as an excrementitious fluid as it is as a means for the regulation of the temperature of the body.

The sweat is a product of the secretory activity of specialized glands, the sweat-glands, embedded in the skin, to the histologic structures of which they bear a special relation.

THE SKIN.

The skin is a complexly organized structure investing the entire external surface of the body. Its total area varies from 16 to 20 feet in man and from 12 to 16 feet in woman. It varies in thickness in different localities of the body from $\frac{1}{8}$ to $\frac{1}{100}$ of an inch. The skin consists of two principal layers: viz., a deep layer, the derma or corium, and a superficial layer, the epidermis.

The **derma** or **corium** may be subdivided into a *reticulated* and a *papillary* layer. The reticulated layer consists of white fibrous and yellow elastic tissue, non-striated muscle-fibers, woven together in every direction and forming an areolar network, in the meshes of which are deposited masses of fat and a structureless amorphous matter; the papillary layer consists mainly of club-shaped elevations or projections of the amorphous matter constituting the papillæ. The reticulated layer serves to connect the skin with the underlying structures and to afford support for the blood-vessels, nerves, and lymphatics which are distributed to the papillæ (Fig. 224).

The **epidermis** is an extra-vascular structure consisting entirely of epithelial cells. It may also be subdivided into two layers—the *Malpighian* or *pigmentary* layer, and the *corneous* or *horny* layer. The former is closely applied to the papillary layer of the true skin and is composed of large nucleated cells, the lowest layer of which, the "prickle cells," contains the pigment granules which give to the skin its varying hues in different individuals and in different races of men; the corneous layer is composed of flattened cells which from their exposure to the atmosphere, etc., are hard and horny in texture.

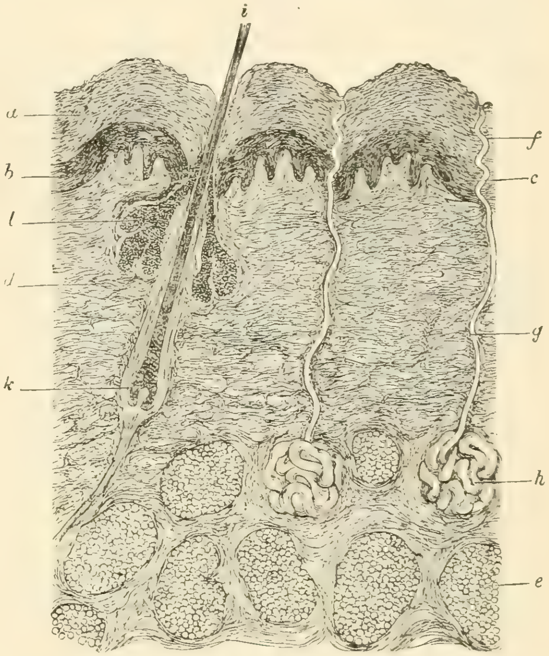


Fig. 224.—Section Perpendicularly Through the Healthy Skin. *a*. Epidermis or scarfskin. *b*. Rete mucosum, or rete malpighii. *c*. Papillary layer. *d*. Derma, corium, or true skin. *e*. Panniculus adiposus, or fatty tissue. *f*, *g*, *h*. Sweat-gland and duct. *i*, *k*. Hair, with its follicle and papilla. *l*. Sebaceous gland.

The Sweat-glands.—These glands are tubular in shape, the inner extremity of each being coiled upon itself a number of times, forming a little ball situated in the derma or the subcutaneous connective tissue. From this coil the duct passes up in a straight direction to the epidermis, where it makes a few spiral turns, after which it opens obliquely on the surface. The gland consists of a basement membrane lined with epithelial cells. It is supplied abundantly with blood-vessels and nerves. The sweat-glands are extremely numerous all over the cutaneous surface, though they are more thickly disposed in some situations than others. They probably average 2500 to the square inch; the total number has been estimated at from 2,000,000 to 2,500,000.

The Influence of the Nerve System on the Production of Sweat.—The secretion of sweat, though a product of the activity of epithelial cells and dependent on a variety of conditions, is regulated to a large extent by the nerve system. Here as in other secreting glands the fluid is derived from materials in the lymph-spaces, furnished by the blood. Generally the two conditions, increased blood-flow and increased glandular action, coexist. At times, however, a profuse clammy perspiration is secreted with diminished blood-flow. Two sets of nerves are evidently concerned in this process: viz., *vaso-motor nerves*, which regulate the blood-supply, and *secretor* nerves, which stimulate the gland cells to activity.

The nerve-centers which control the sweat-glands are situated in the spinal cord, though the number of such centers and their exact location for the different regions of the body have not yet been satisfactorily determined. In a general way it may be stated that the centers for the head and face lie in the upper cervical portion of the cord; for the upper extremities, in the lower cervical portion; for the lower extremities, in the lower dorsal and upper lumbar portion. The secretor nerves which emerge from these centers reach the glands of the face and head through the cervical sympathetic; of the arms and legs, through the brachial plexus and the sciatic nerves. It is probable that there is also a general dominating sweat center located in the medulla oblongata.

That the sweat-glands are stimulated to activity by nerve impulses is shown by the fact that stimulation of the peripheral end of the divided cervical sympathetic, of the brachial plexus, or of the sciatic nerve is followed in a few seconds by a profuse secretion. Though under physiologic conditions there is a simultaneous dilatation of the blood-vessels and an increased supply of blood, this is merely a condition and not a cause of the secretion; for the secretion can be excited and the flow maintained for a period of from ten to fifteen minutes after ligation of the blood-vessels of the limb or even after its amputation, when the corresponding nerve is stimulated.

The sweat-glands may be excited to activity by their related nerve-centers, either by central, reflex, or peripheral influences. Among the first may be mentioned mental emotions, venosity of the blood, increased temperature of the blood, hot drinks, violent muscular exercise, etc. Among the second may be mentioned powerful stimulation of various afferent or sensor nerves, heightened external temperature, etc. Among the last may be mentioned various drugs. Pilocarpin injected into the blood causes a profuse secretion even when the nerves have been divided. Its action is supposed to be exerted on the terminal branches of the nerves and possibly on the cells themselves. As in the case of the salivary glands atropin suspends the activity of the terminal branches of the secretor nerves.

Hairs.—Hairs are found in almost all portions of the body, and can be divided into—

1. Long, soft hairs, on the head.
2. Short, stiff hairs, along the edges of the eyelids and nostrils.
3. Soft, downy hairs on the general cutaneous surface.

They consist of a *root* and a *shaft*. The shaft is oval in shape and about $\frac{1}{400}$ of an inch in diameter; it consists of fibrous tissue, covered externally by a layer of imbricated cells, and internally by cells containing granular and pigment material.

The *root* of the hair is embedded in the hair-follicle, formed by a tubular depression of the skin, extending nearly through to the subcutaneous tissue; its walls are formed by the layers of the corium, covered by epidermic cells. At the bottom of the follicle there is a papillary projection of amorphous matter, corresponding to a papilla of the true skin, containing blood-vessels and nerves, upon which the hair-root rests. The investments of the hair-roots are formed of epithelial cells, constituting the *internal* and *external* root-sheaths.

The lower portion of the hair-follicle is connected with the upper surface of the derma by bundles of non-striated muscle-fibers which are termed *arrectores pilorum* muscles. Their inclination and insertion are such that their contraction is followed by erection of the hair-follicle and hair-shaft. These muscles are excited to action by nerves termed *pilo-motor* nerves.

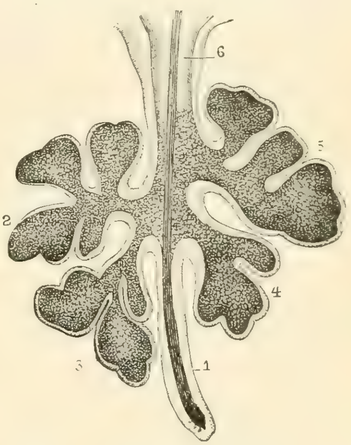


FIG. 225.—LARGE SEBACEOUS GLAND. 1. Hair in its follicle. 2, 3, 4, 5. Lobules of the gland. 6. Excretory duct traversed by the hair. —(*Sappey.*)

THE SEBUM.

The **sebum** or **sebaceous matter** is a peculiar oily material produced by specialized glands in the skin. It consists of water, epithelium, proteids, fat, cholesterin, and inorganic salts.

The **sebaceous glands** are simple and compound racemose glands opening by a common excretory duct on the surface of the epidermis or into the shaft of a hair-follicle (Fig. 225). These glands are extremely numerous and found in all portions of the body, with the exception of the palms of the hands and soles of the feet, and most abundantly in the face. They are formed by a delicate structureless membrane lined by polyhedral epithelium.

The sebum is not produced by an act of true secretion, but is formed by a proliferation and degeneration of the gland epithelium. When first poured on the surface, the sebum is oily and semiliquid in character, but soon hardens and acquires a cheese-like consistence. It serves to lubricate the hair and skin and prevent them from becoming dry and harsh.

The surface of the fetus is generally covered with a thick layer of sebaceous matter, the *vernix caseosa*, which possibly keeps the skin in a normal condition by protecting it from the effects of the long-continued action of the amniotic fluid in which the fetus is suspended.

CHAPTER XIX.

THE CENTRAL ORGANS OF THE NERVE SYSTEM AND THEIR NERVES.

The **central organs of the nerve system** are the encephalon and the spinal cord lodged within the cavity of the cranium and the cavity of the spinal or vertebral column respectively. The general shape of these two portions of the nerve system corresponds with that of the cavities in which they are contained. The encephalon is broad and ovoid, the spinal cord is narrow and elongated.

The **encephalon** is subdivided by deep fissures into four distinct, though closely related portions: viz., (1) the cerebrum, the large ovoid mass, occupying the entire upper part of the cranial cavity; (2) the cerebellum, the wedge-shaped portion placed beneath the posterior part of the cerebrum and lodged within the cerebellar fossæ of the cranium; (3) the isthmus of the encephalon, the more or less pyramidal-shaped portion connecting the cerebrum and cerebellum with each other and both with (4) the medulla oblongata. (Fig. 226.)

The **spinal cord** is narrow and cylindric in shape. It occupies the spinal canal as far as the second or third lumbar vertebra. The central nerve system is bilaterally symmetric, consisting of distinct halves united in the median line. The cerebrum is subdivided by a deep fissure, running antero-posteriorly, into two ovoid masses termed *cerebral hemispheres;* the cerebellum is also partially subdivided into hemispheres; the isthmus likewise presents in the median line a partial division into halves; the medulla oblongata and spinal cord are subdivided by an anterior or ventral and a posterior or dorsal fissure into halves, a right and a left.

The **peripheral organs of the nerve system** in anatomic and physiologic relation with the central organs are the encephalic and the spinal nerves. The **encephalic nerves,** twelve in number on each side of the median line, are in relation with the base of the encephalon, and because of the fact that they pass through foramina in the walls of the cranium they are usually termed cranial nerves.

The **spinal nerves,** thirty-one in number on each side, are in relation with the spinal cord, and because of the fact that they pass through foramina in the walls of the spinal column they are termed spinal nerves. As both cranial and spinal nerves are ultimately distributed to the structures of the body—*i. e.*, the general periphery—they collectively constitute the *peripheral organs of the nerve system.*

The central organs of the nerve system are supported and protected by three membranes named, in their order from without inward, the dura mater, the arachnoid, and the pia mater.

The *dura mater* is a tough membrane composed of fibrous tissue. It consists of two layers, the outer of which lines the cranial cavity and forms an internal periosteum; the inner layer is closely attached to the outer except at certain regions where it separates and forms supporting structures, such as the falx cerebri, falx cerebelli, tentorium cerebelli, etc.; at the margin of the foramen magnum the outer layer becomes continuous with the periosteal tissue, while the inner layer invests the cord down to its ultimate termination. (Fig. 227.)

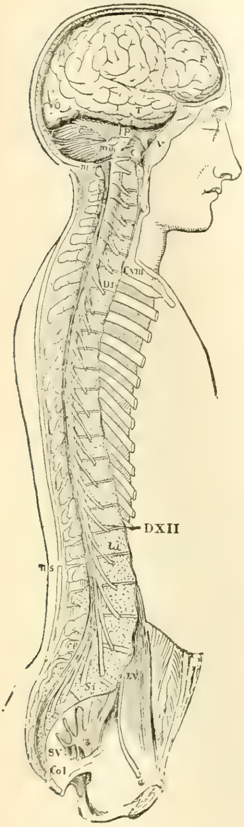


FIG. 226.—THE CENTRAL ORGANS OF THE NERVE SYSTEM. F. T. O. Frontal, temporal, and occipital lobes of the cerebrum. C. Cerebellum. P. Pons. *mo.* Medulla oblongata. *ms.*, *ms.* The upper and lower limits of the spinal cord. The remaining letters indicate the region and number of the spinal nerves.—(*Quain, after Bourgery.*)

The *arachnoid* is a delicate serous membrane. The external surface is smooth and well defined and separated from the dura by a narrow space, the subdural space. The inner surface sends inward fine connective-tissue processes which interlace in every direction, constituting the subarachnoid tissue. This tissue is abundant in the cranium, much less so in the spinal canal. The spaces between the connective tissue, taken collectively, constitute the general subarachnoid space. Around the spinal cord this space is well defined, and at the base of the encephalon expands to form large cavities known as the cisterna magna, cisterna pontis, etc.

The *pia mater* is a delicate membrane composed of areolar tissue. It closely invests the encephalon and spinal cord, dipping into the various fissures. It is exceedingly vascular and sends small blood-vessels for some distance into the brain and spinal cord.

The Encephalo-spinal Fluid.—The general subarachnoid space, as well as certain cavities within the encephalon, contain a clear transparent fluid, termed the encephalo-spinal. This fluid has an alkaline reaction and a specific gravity of 1.007 or 1.008. It is composed of water, proteids (proteoses and serum-globulin), and a compound pyrocatechin, capable of reducing copper salts, though not exhibiting any other of the properties of sugar. In many respects this fluid resembles lymph. The subarachnoid space and the general encephalic cavities, termed ventricles, communicate with one another by an opening in the pia mater (the foramen of Magendie) as it passes over the lower part of the fourth ventricle.

It was stated in Chapter VIII that the entire nerve or neuron system can be resolved into a single morphologic unit, the neuron: the histologic features and the physiologic properties of the neuron were there also described; the anatomic relation of the neurons constituting the peripheral organs of the nerve system, to the neurons constituting the central organs of the nerve system were also stated and illustrated in part diagrammatically, page 125. From the statements made regarding the functions of the different neurons in their individual and collective capacity the functions of the nerve system will become apparent.

The Functions of the Nerve System.—The functions of the nerve system are twofold: (1) It unites and coördinates the organs and tissues of the body in such a manner that they are enabled to coöperate for the accomplishment of a definite object. (2) It serves to arouse in the individual a consciousness of the existence of an external world, by virtue of the impressions which it makes on his sense organs, and consequently to enable him to adjust himself to his environment.

By virtue of the coördination, a stimulus, if of sufficient intensity, applied to one organ or tissue will call forth activity in one or more organs near or remote from the part stimulated. This coördination is accomplished mainly by the spinal cord and the medulla oblongata. All actions which take place in response to a peripheral stimulus and independently of volition are termed reflex actions. The reflex activities connected with digestion, the circulation of the blood, with respiration, excretion, etc., are illustrations of the coördinating capabilities of the nerve-centers located in these portions of the central nerve system.

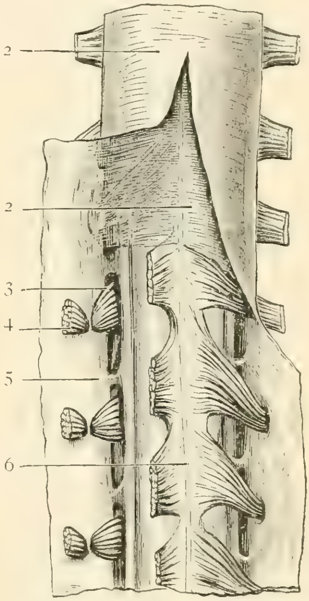


FIG. 227.—THE MEMBRANES OF THE SPINAL CORD. 1. Dura mater. 2. Arachnoid. 3. Posterior root of spinal nerve. 4. Anterior root of spinal nerve. 5. Ligamentum dentatum. 6. Linea splendens.—(*Morris, after Ellis.*)

Consciousness of the existence of the external world and of the relation existing between it and the individual is associated with the physiologic activities of the encephalon, and more particularly of the cerebral hemispheres. This portion of the nerve system is the chief, though perhaps not the sole, organ of the mind, and its main functions are for the most part mental.

The function of a part at least of the peripheral nerve system is to afford a means of communication between the central nerve system and the remaining structures of the body. The nerve-trunks constituting this part may be divided into two groups, as follows:

1. The first group comprises nerves in connection with the special sense-organs, *e. g.*, eye, ear, nose, tongue, skin, as well as nerves in connection with the general or organic sense-organs, *e. g.*, mucous membranes, viscera, etc., which transmit nerve impulses to certain localized areas in the cerebral cortex, where they are translated into conscious sensations. These sensations, both special and general, by their grouping and combinations are the primary elements of intelligence.
2. The second group comprises those nerves which terminate in the muscle apparatus and which transmit nerve impulses, by way of the medulla and spinal cord, from localized areas in the cerebral cortex to the muscles of the face, trunk and extremities, which are in consequence excited to activity. The muscle movements thus become physical expressions of mental states, and if directed in a definite manner to the overcoming of the resistances offered by the external world become capable of modifying it in accordance with the mental states.

The first group of nerves, the afferent, especially those connected with the special sense-organs, are excited to activity by impressions made on their peripheral terminations by agencies in the external world, and thus become a means of communication between the physical and the mental worlds.

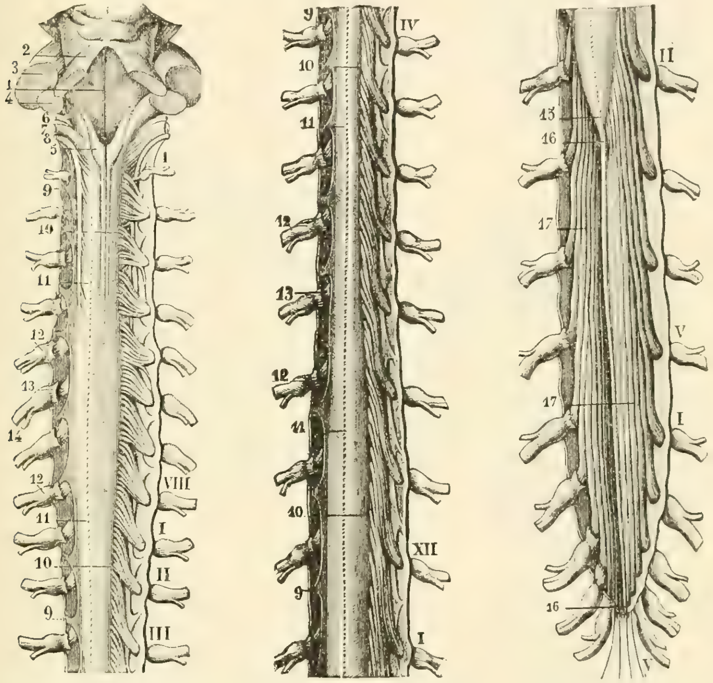
The second group of nerves, the efferent, are excited to activity by those molecular disturbances in their related nerve-cells which accompany volitional efforts, and thus they become a means of communication between the mental and the physical worlds.

The central nerve system is thus composed of a number of separate though closely related parts, to each of which a separate function has been assigned. In the study of the structure and function of these separate parts it will be found convenient, and conducive to clearness, to consider them in the order of their complexity, beginning with the spinal cord and ending with the cerebrum.

THE SPINAL CORD.

The **spinal cord** is the narrow elongated portion of the central nerve system contained within the spinal canal. It is cylindric in shape though presenting an enlargement in both the lower cervical and lower lumbar regions corresponding to the origins of the nerves distributed to the upper and lower extremities. The cord varies in length from 40 to 45 cm., measures 12 mm. in diameter, weighs 42 gms., and extends from the atlas to the second lumbar vertebra, beyond which it is continued as a narrow thread, the *filum terminale*. (Fig. 228.) It is divided by the anterior and posterior longitudinal fissures into halves, and is therefore bilaterally symmetric. A transverse section of the cord shows that it is composed of both white and gray matter, the former covering the surface, the latter occupying the center.

Structure of the Gray Matter.—The gray matter is arranged in the form of two crescents, united in the median line by a transverse band or commissure forming a figure resembling the letter **H**. Though varying in shape in different regions of the cord, the gray matter in all situations presents on either side an anterior or ventral and a posterior or dorsal horn. Between the two horns there is a portion termed the intermediate gray substance. The commissure presents in its center a narrow canal which extends throughout the entire length of the cord. This canal is lined by cylindric epithelium and surrounded by gelatinous material. (Fig. 229.)



Superior or Cervical Segment of Spinal Cord. Middle or Dorsal Portion of Cord. Inferior Portion of Cord and Cauda Equina.

FIG. 228.—SUPERIOR, MIDDLE, AND INFERIOR PORTIONS OF SPINAL CORD. 1. Floor of fourth ventricle. 2. Superior cerebellar peduncle. 3. Middle cerebellar peduncle. 4. Inferior cerebellar peduncle. 5. Enlargement at upper extremity of postero-median column. 6. Glosso-pharyngeal nerve. 7. Vagus. 8. Spinal accessory. 9, 9, 9, 9. Ligamentum denticulatum. 10, 10, 10, 10. Posterior roots of spinal nerves. 11, 11, 11, 11. Postero-lateral fissure. 12, 12, 12, 12. Ganglia of posterior roots. 13, 13. Anterior roots. 14. Division of united roots into anterior and posterior nerves. 15. Terminal extremity of cord. 16, 16. Filum terminale. 17, 17. Cauda equina. I, VIII. Cervical nerves. I, XII. Dorsal nerves. I, V. Lumbar nerves. I, V. Sacral nerves.—(*Sappey*.)

The *anterior horn* is short and broad and entirely surrounded by white matter. The *posterior horn* is narrow and elongated and extends quite up to the surface of the cord, where it is capped by gelatinous matter, the *substantia gelatinosa*. In the lower cervical and thoracic regions a portion of the intermediate gray substance projects outward and forms the so-called lateral horn. The gray matter fundamentally consists of a framework of fine neuroglia supporting blood-vessels, lymphatics, medullated and non-medullated nerves, and groups of nerve-cells.

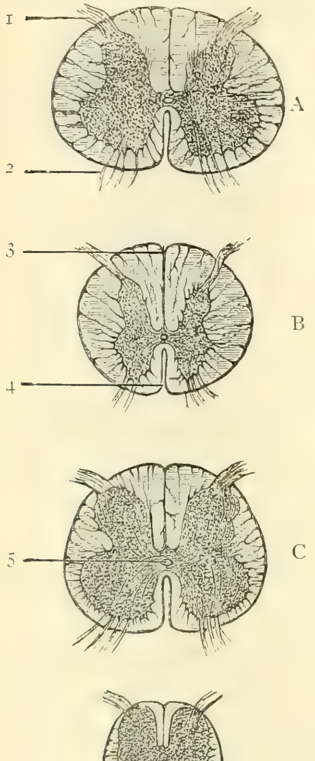


Fig. 229.—Sections through Different Regions of the Spinal Cord. A. At the level of the sixth cervical nerve. B. At the mid-dorsal region. C. At the center of the lumbar enlargement. D. At the upper part of the conus medullaris. 1. Posterior roots. 2. Anterior roots. 3. Posterior fissure. 4. Anterior fissure. 5. Central canal.—(*Morris' "Anatomy," after Schwalbe.*)

The Nerve-cells.—The nerve-cells of the cord are very numerous and present a variety of shapes and sizes in different regions. They are usually arranged in groups which extend for some distance up and down the cord, forming columns more or less continuous.

In the anterior horn two well-marked groups are found, one situated at the anterior and inner angle, known as the antero-median group, the other situated at the posterior and lateral angle and known as the postero-lateral group. In the lower cervical and upper thoracic regions, in the region of the lateral horn, another group of cells is found, known as the intermediate group. In the central portion of the horn there is also a central group.

The cells of the anterior horns are of large size, nucleated and multipolar. They are the modified descendants of pear-shaped cells, the neuroblasts, which migrated from the medullary tube (see page 105). In the course of their migration they developed dendrites which form an intricate felt-work throughout the anterior horn. One of the processes, the axon, approached the surface of the cord, penetrated it, grew outward, became covered with myelin and neurilemma, and developed into an anterior root-fiber. These nerve-cells, with their dendrites, axons, and terminal branches, form efferent neurons of the first order. The intimate histologic and physiologic relationship existing between the nerve-cell and the axon is revealed by the degenerative changes which arise in the latter when separated from the former. The cell apparently determines the nutrition of the axon and may be regarded as trophic in function. Some of the cells of the anterior horn send their axons into the immediately surrounding white matter of the same side, after which they divide into two branches, one passing up, the other down, the cord, to re-enter the gray matter at different levels. They are probably associative in function. Other cells send their axons into that portion of the white matter on the same and opposite sides known as Gower's antero-lateral tract. (Fig. 230.)

In the posterior horn nerve-cells are also present, though they are not so numerous as in the anterior horn. At the base of the horn and on its inner side there is a well-marked group of cells which extends from the seventh or eighth cervical nerves downward to the second or third lumbar nerves, being most prominent in the thoracic region. This column is known as Clarke's vesicular column. From the nerve-cells constituting this column axons pass obliquely outward into that portion of the white matter known as the direct cerebellar tract. Other nerve-cells send their axons into the white matter in the posterior portion of the cord bordering the posterior median fissure. Some of the nerve-cells, their situation and the distribution of their axons are shown in Fig. 230.

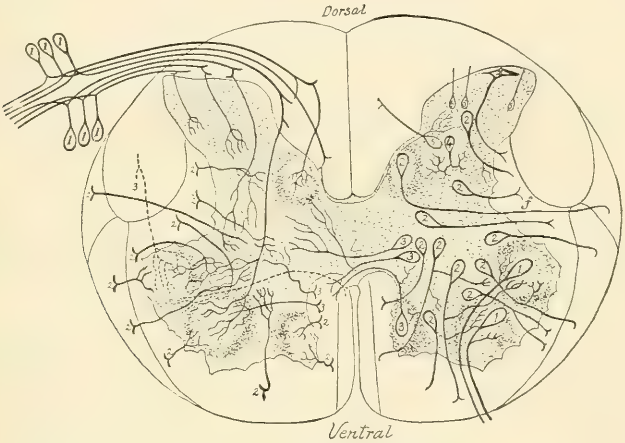


FIG. 230.—SCHEME OF THE STRUCTURE OF THE CORD.—(*Howell after Lenhossek.*) On the right the nerve cells; on the left the entering nerve fibers. Right side: 1, Motor cells, anterior horn, giving rise to the fibers of the anterior root; 2, tract cells whose axons pass into the white matter of the anterior and lateral columns; 3, commissural cells whose axons pass chiefly through the anterior commissure to reach the anterior columns of the other side; 4, Golgi cells (second type), whose axons do not leave the gray matter; 5, tract cells whose axons pass into the white matter of the posterior column. Left side: 1, Entering fibers of the posterior root, ending, from within outward, as follows: Clarke's column, posterior horn of opposite side, anterior horn same side (reflex arc), lateral horn of same side, posterior horn of same side; 2, collaterals from fibers in the anterior and lateral columns; 3, collaterals of descending pyramidal fibers ending around motor cells in anterior horn.

Classification of Nerve-cells.—The cells of the gray matter may be divided into three main groups: viz., intrinsic, efferent, and afferent.

The *intrinsic cells* are associative in function. The axons to which these cells give origin pass more or less horizontally into the white matter, where they divide into two branches, one of which passes upward, the other downward. At various levels they re-enter the gray matter and arborize around other intrinsic cells.

The *efferent cells*, independently of their trophic influence, are also motor in function, inasmuch as the excitation arising in them is transmitted outwardly through their axons to muscles, blood-vessels, glands and viscera, imparting to them motion, either molar or molecular. As the efferent fibers in the ventral roots of the spinal nerves are classified (see page 107) in accordance with their physiologic action into motor, vaso-motor, secretor, viscero-motor and pilo-motor nerves, so the nerve-cells of which the nerves are integral parts may be classified physiologically as motor, vaso-motor, secretor, viscero-motor and pilo-motor. Collections or groups of such cells are termed "centers."

The *afferent cells* are largely sentient or receptive in function, inasmuch as the excitations brought to the spinal cord by the afferent nerves in the dorsal roots from the general periphery are received by them and transmitted by and through their axons to the cortex of the cerebrum, where they are translated into conscious sensations. As the nerve-fibers in the dorsal roots of the spinal nerves are classified, in accordance with the sensations to which they give rise, as sensor, thermal, tactile, etc., so these nerve-cells may be similarly classified according as they transmit their excitations to those specialized areas in the cerebral cortex in which these different sensations arise.

Structure of the White Matter.—A transverse section of the cord shows that the white matter completely covers the gray matter except where the posterior horns reach the surface. Anteriorly the white matter of each lateral half is connected by a narrow strip or bridge of white matter, the anterior commissure. Microscopic examination shows that the white matter is composed of vertically disposed medullated nerve-fibers which are devoid of a neurilemma. These fibers are supported partly by a framework of connective tissue, and partly by neuroglia. The white matter of each side of the cord is anatomically divided into an anterior, a lateral, and a posterior column by the anterior and posterior roots of the spinal nerves.

Classification of the Nerve-fibers.—From a study of the embryologic development of the white matter and of the degenerative changes which follow its pathologic and experimental destruction, it has been differentiated into a number of specialized tracts which have different origins, destinations, and functions. Some of the more important tracts are shown in Fig. 231. They may be divided, however, into efferent, afferent, and associative fibers.

1. The **anterior column**, comprising that portion between the anterior longitudinal fissure and the anterior roots, has been subdivided into:

(*a*) The *direct pyramidal tract*, or column of Türck. This tract borders the longitudinal fissure and extends from the upper extremity of the cord as far down as the mid-thoracic region. From above downward this tract diminishes in size, for the reason that its fibers or their collaterals cross at successive levels to the opposite side of the cord by way of the anterior commissure to enter the gray matter of the anterior horn. These fibers are the continuations of fibers which take their origin in cells which are located in the cortex of the cerebral hemisphere of the same side. The terminal filaments of these fibers or axons are in physiologic relation either directly or indirectly through intercalated neuron cells with the dendrites of the cornual cells. When divided in any part of their course, these fibers undergo descending degeneration. They are therefore efferent neurons and of the second order.

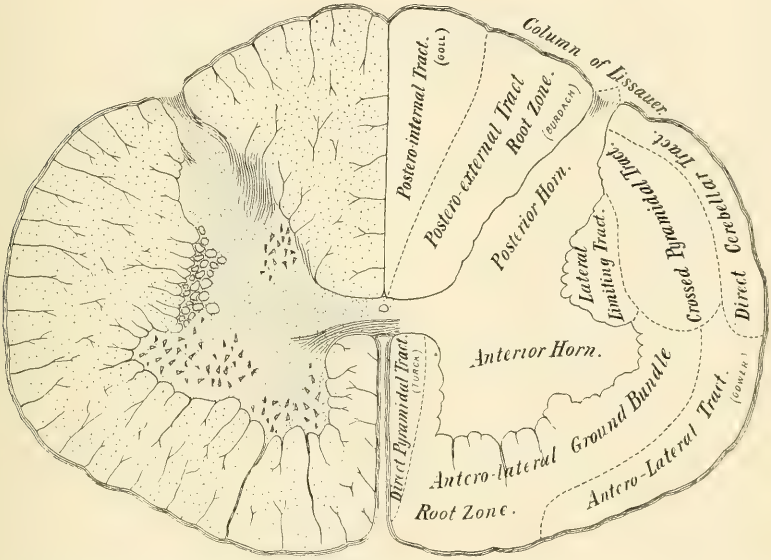

Postero-internal Tract.
(GOLL)
Column of Lissauer.
Postero-external Tract
Root Zone.
(BURDACH)
Posterior Horn.
Crossed Pyramidal Tract.
Direct Cerebellar Tract.
Lateral Limiting Tract.
Anterior Horn.
Direct Pyramidal Tract.
(TURCK)
Antero-lateral Ground Bundle
Root Zone.
Antero-Lateral Tract.
(GOWER)

FIG. 231.—TRANSECTION OF THE CERVICAL SPINAL CORD SHOWING ITS CHIEF SUBDIVISIONS.—(*After Mills.*)

(*b*) The *antero-lateral ground bundle or root zone.* This tract lies external to the pyramidal tract, surrounds the anterior horn of the gray matter and extends throughout the length of the cord. It is composed of short commissural or associative fibers which come from nerve-cells in the gray matter from the same and opposite sides of the cord. After entering the white matter they divide into two branches, pursue opposite directions, then re-enter the gray matter at higher and lower levels and come into relation with other nerve-cells.

2. The **lateral column,** comprising that portion between the ventral and dorsal roots, has been divided into:

(*a*) The *antero-lateral tract* of Gowers. This tract is somewhat crescentic in shape and situated on the lateral aspect of the cord external to the antero-lateral root zone. It extends throughout the entire length of the cord. When divided it undergoes ascending degeneration, which would indicate that the axons originate in nerve-cells in the gray matter. This tract is therefore afferent in function.

(*b*) The *lateral limiting tract*. This tract, which is quite narrow, lies close to the external border of the gray matter. It is composed of fibers which do not degenerate to any considerable extent and are in all probability associative fibers which come from nerve-cells in the gray matter to re-enter at lower and higher levels. It is also believed by some investigators that the anterior portion contains efferent and the posterior portion afferent fibers; for this reason it is frequently termed the mixed lateral tract.

(*c*) The *crossed pyramidal tract*. This tract occupies the posterior portion of the lateral column, though its exact position varies somewhat in different regions of the cord. In the cervical and thoracic regions it is covered by a layer of fibers. In the lumbar region, however, it comes to the surface. From above downward this tract gradually diminishes in size, for the reason that its fibers and their collaterals enter the gray matter at successive levels. The terminal branches of these fibers are in close physiologic relation either directly or indirectly through intercalated neuron cells with the dendrites of the cornual cells. These fibers are the continuations of fibers which take their origin in cells which are located in the cortex of the cerebral hemispheres of the opposite side. When divided in any part of their course, they undergo descending degeneration. They are therefore efferent neurons and of the second order.

(*d*) The *direct cerebellar tract*, or column of Flechsig. This tract is situated on the surface of the lateral column external to the crossed pyramidal tract. It slightly increases in size from below upward. It is composed of fibers the cells of which are found on the inner side and base of the posterior horn (Clark's vesicular column). From this origin the fibers pass obliquely outward to the surface and then directly upward to terminate, as its name implies, in the cerebellum. Decussation of these fibers takes place in the superior vermiform lobe of the cerebellum. When divided this tract degenerates upward. It is therefore in all probability an afferent tract and of the second order.

3. The **posterior column,** comprising that portion between the dorsal roots and the posterior longitudinal fissure, has been subdivided into:

(*a*) The *postero-external tract* of Burdach. This tract lies just within the posterior horns. A portion of this tract is composed of ground fibers which, though vertically disposed, have but a short course. They take their origin in cells in the gray matter, and after entering this tract divide into ascending and descending branches, which with their collaterals re-enter the gray matter at different levels. Another portion of this tract is made up of nerve-fibers derived from the dorsal roots of the spinal nerves, which cross this column toward the median line in an oblique or horizontal direction. The fibers of the upper portion of this tract terminate around the *nucleus cuneatus* at the medulla oblongata. When divided, these fibers degenerate for but a short distance. The ground fibers are probably associative in function.

(*b*) The *postero-internal tract*, or column of Goll. This tract is separated from the former by a septum of connective tissue which is most marked above the eleventh thoracic segment. The fibers which compose this tract are long and derived for the most part from the dorsal roots of the spinal nerves of *the same side*. This is shown by the fact that division of these roots central to the ganglion is followed by ascending degeneration of the column of Goll as far as the *nucleus gracilis* in the medulla oblongata. Fibers derived from cells in the gray matter are also contained in this column. This tract is largely afferent in function.

(*c*) *Lissauer's tract*. This tract embraces the tip of the posterior horn and is composed principally of fibers from the dorsal roots of the spinal nerves. After entering the tract the fibers divide into ascending and descending branches, which finally terminate around cells in the posterior horn.

In addition to the tracts described in foregoing paragraphs a number of small narrow tracts have been discovered in different regions of the spinal cord the functional significance of which, however, has not been determined. Of these may be mentioned:

1. The *antero-lateral tract* of Marchi and Löwenthal, situated at the anterior and inner angle of the anterior column, which degenerates downward after removal of one-half of the cerebellum.
2. The *comma tract* a narrow bundle of fibers situated in the anterior portion of the column of Burdach. When it is divided it degenerates downward.
3. The *septo-marginal tract*, an oval shaped tract situated along the margin of the posterior longitudinal fissure.
4. The *cornu-commissural tract* found along the border of the anterior portion of the posterior column as far forward as the posterior commissure. Both of these tracts are best developed in the lumbosacral region. They arise from nerve-cells in the gray matter. They undergo descending degeneration when divided, but not after division of the dorsal roots.

The Relation of the Spinal Nerves to the Spinal Cord.—The spinal nerves present near the spinal cord two divisions which from their connection with the anterior or ventral and the posterior or dorsal surfaces are known as the ventral and dorsal roots.

The *ventral* roots are the axons of various groups of nerve-cells situated in the anterior horns of the gray matter. From their origin these axons pass almost horizontally forward through the anterior column in three distinct bundles. After emerging from the cord they curve downward and backward to join the dorsal roots. The *dorsal* roots are the centrally directed axons of nerve-cells in the spinal ganglia. After entering the cord they divide into two main groups, a lateral and a mesial. A portion of the lateral group enters the posterior horn directly through the caput cornu; the other portion turns upward and runs through Lissauer's tract and ultimately enters the posterior horn. The mesial group passes into the postero-external column (Burdach), where the fibers divide into descending and ascending branches. The former constitute the comma tract, the terminal branches of which surround cells in the gray matter; the latter (ascending) cross the column obliquely and enter the postero-internal column (Goll), in which they pass upward to terminate around the cells of the nucleus gracilis of the same side. As these root fibers pass up and down the cord, collateral branches are given off which enter the gray matter at successive levels and come into physiologic relation with the cells of Clark's vesicular column on the same and opposite sides and with the cells of the anterior horn.

The peripherally directed axons of the nerve-cells in the spinal nerve ganglia become associated with the axons of the ventral roots and together they pass as a spinal nerve to peripheral organs.

The ventral root axons are distributed to skeletal muscles, blood-vessels, glands and viscera. The dorsal root axons are distributed to skin, mucous membranes and muscles. The classification of the nerve-fibers in the ventral and dorsal roots in accordance with the functions they subserve will be found on pages 107, 108.

Though both the efferent and afferent fibers of the spinal nerves are directly connected with nerve-cells in the spinal cord, they are also indirectly connected by efferent and afferent nerve-tracts with the cerebral cortex.

Experimentally, it has been determined that the anterior or ventral roots contain all the *efferent* fibers, the posterior or dorsal roots all the *afferent* fibers. The proofs in support of this view are as follows:
Stimulation of the ventral roots produces:

1. Tetanic contraction of skeletal muscles.
2. Variations in the degree of the contraction, the tonus, of the muscle walls of the peripheral arteries either in the way of augmentation or inhibition.
3. Discharge of secretions from glands.
4. Variations in the degree of the contraction, the tonus, of the muscle walls of certain viscera either in the way of augmentation or inhibition.

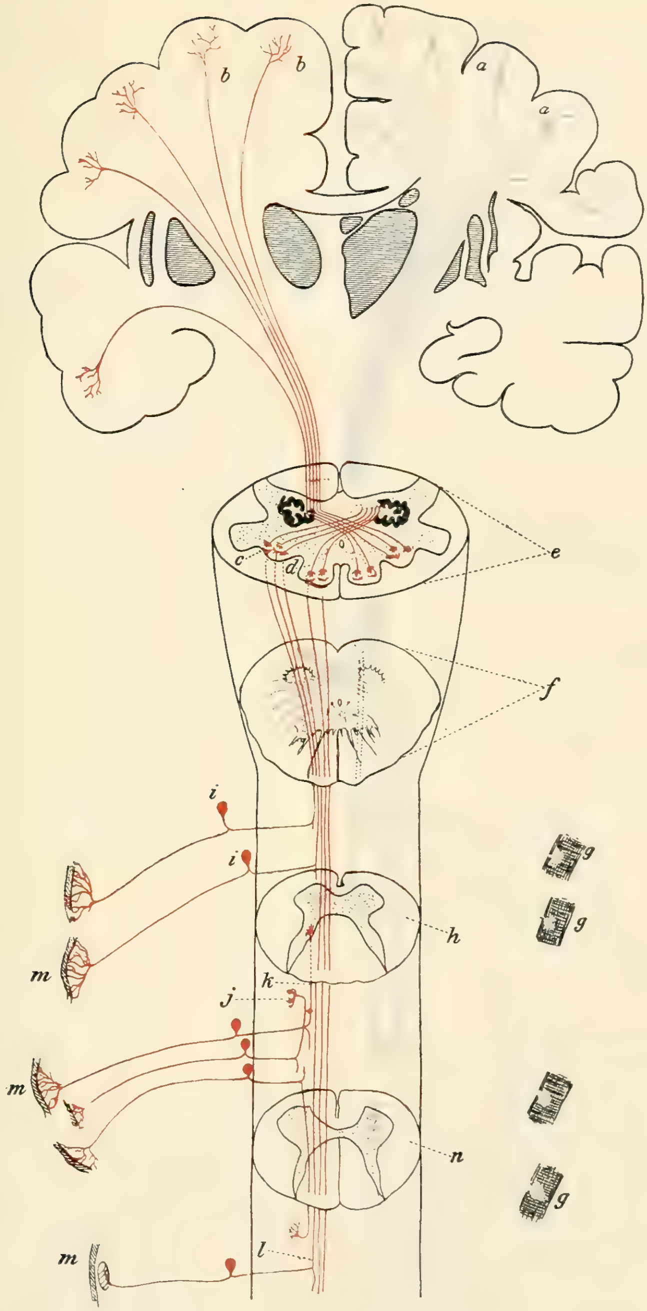
Division of the ventral roots is followed by:

1. Relaxation of skeletal muscles and loss of movement.
2. Temporary dilatation and loss of the tonus of blood-vessels.
3. Cessation in the discharge of secretions from glands.

Diagram Indicating the Course of the Motor and Sensory Fibers of the Spinal Cord and Medulla.—(*Gordinier.*)

a, a. Motor cells of the cerebral cotrex. *b, b.* Arborizations of the fibers of the sensory tract in the cerebral cortex. *c.* Nucleus of the column of Burdach, showing terminal arborizations of the long sensory fibers of the cord. *d.* Nucleus of the column of Goll, showing terminal arborizations of the long sensory fibers of the cord. *e.* Section of the medulla, showing sensory decussation. *f.* Section of medulla, showing motor or pyramidal decussation. *g, g.* Motorial end plates. *h.* Section through the cervical region of the cord, showing termination in the anterior horn of the motor fibers of the direct pyramidal tract after they have crossed in the anterior commissure; also fiber of crossed pyramidal tract ending about anterior horn cell of same side, *i, i.* Posterior spinal ganglia. *j, k.* Sensory fibers of short course. *l.* Sensory fibers of long course, terminating in medulla. *m, m, m.* Sensory end organs. *n.* Section through lumbar cord.

PLATE II.



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4. Temporary impairment of the normal activities of the visceral muscles from loss of central nerve control; the degree of impairment depending on the nature of the viscus involved.

Peripheral stimulation of the dorsal roots produces:

1. Sensations of touch, temperature, pressure and pain.
2. Reflex excitation of spinal nerve centers in consequence of which there is an increased activity of skeletal muscles, blood-vessels, glands and visceral walls.
3. Reflex inhibition of spinal nerve centers in consequence of which there may be a decrease in the activities of skeletal muscles, blood-vessels, glands and viscera.
4. Sensations of the duration and direction of muscle movements, of the resistance offered and of the position of the body or of its individual parts (muscle sensations).

Division of the dorsal roots is followed by:

1. Loss of sensation in all parts to which they are distributed.
2. Loss of the power of exciting or inhibiting reflexly the activities of spinal nerve centers and in consequence a loss of the power of exciting or inhibiting the activities of peripheral organs.

The ventral roots are therefore efferent in function transmitting nerve impulses from the spinal cord to the peripheral organs which excite them to activity.

The dorsal roots are afferent in function transmitting nerve impulses from the general periphery to (*a*) the spinal cord where they excite its contained nerve-centers to activity, and (*b*) to the cerebrum where they excite its centers to activity with the development of sensations.

Segmentation of the Spinal Cord.—For the elucidation of many problems connected with the physiologic actions of the spinal cord, as well as of the symptoms which follow its pathologic impairment, it will be found helpful to consider the cord as consisting physiologicly of a series of segments placed one above the other, the number of segments corresponding to the number of spinal nerves. Each spinal segment would therefore comprise that portion of the cord to which is attached a pair of spinal nerves. The nerve-cells in each segment are in histologic and physiologic relation with definite areas of the body, embracing muscles, blood-vessels, glands, skin, etc.

If the exact distribution of the nerves of any segment were then known, its function could be readily stated. By virtue of this segmentation it becomes possible for each segment to act independently, or in coöperation with other segments near or remote, with which they are associated by the intrinsic or associative cells and their axons; and the spinal cord itself is enabled to act as a unit.

FUNCTIONS OF THE SPINAL CORD.

Physiologic investigation has demonstrated that the spinal cord, by virtue of the presence of nerve-cells and nerve-fibers, may be regarded as composed of:

1. Independent nerve-centers, each of which has a special function; and—
2. Conducting paths by which these centers are brought into relation with one another and with the cerebrum and its subordinate or underlying parts, *e. g.*, medulla and pons Varolii.

The Spinal Cord Segments as Independent Centers.—The efferent cells of the spinal segments are the immediate sources of the nerve energy which excites activity in muscles, blood-vessels, glands. The discharge of their energy may be caused:

1. By variations in the composition of the blood or lymph by which they are surrounded. The activity of the cell thus occasioned is termed automatic or autochthonic (Gad).
2. By the arrival of nerve impulses coming through afferent nerves from the general periphery, skin, mucous membrane, etc.
3. By the arrival of nerve impulses descending the spinal cord from the cerebrum or subordinate structures. The peripheral activity in the former instance is said to be reflex or peripheral in origin; in the latter instance, direct or cerebral in origin. In this latter instance, also, the muscle movements are due to volitional, the vascular variations and glandular discharges to emotional, forms of cerebral activity.

Each segment of the spinal cord may be regarded, therefore, because of its contained nerve-cells:

1. As a center for automatic activity.
2. As a center for the reception of nerve impulses arising either at the periphery or in the cerebrum, and for their subsequent transmission through efferent nerves to various peripheral organs.

Automatism.—The growth, the nutrition and multiplication of the cells of various tissues, and their continuous and rhythmic activity, have been attributed to an automatic action of the spinal nerve-cells. By this expression is meant a discharge of energy from the cells occasioned by a change in their environment, *i. e.*, in the chemic composition of the blood or lymph by which they are surrounded, and independent of any excitation coming through afferent nerves. If the cell activity is continuous, though variable in degree from time to time, it gives rise to what is termed tonus, *e. g.*, trophic tonus, vascular, muscle tonus, etc. If the cell activity is intermittent, it imparts to muscles a certain rhythmic activity, *e. g.*, the respiratory movements.

As no effect arises without a sufficient cause, the term automatic has been objected to and the term autochthonic has been suggested (Gad), expressive of the idea that the energy originates in the nerve-cell as a result of a reaction between the cell and its ever-changing environment. A center so acting could not be regarded as primarily a center for reflex action, however much it might be influenced or conditioned secondarily by afferent impulses. Though automatic activity of the spinal cord centers is advocated by some physiologists, the fact must be recognized that with increasing knowledge of reflex activities some of the phenomena hitherto regarded as automatic have been found to be reflex in origin. Whether this will eventually be found true for all forms of so-called automatic or autochthonic activity remains to be seen.

Trophic Tonus.—The normal metabolism of muscle, gland, and connective tissue which underlies the assimilation of food, the storing of energy, and the production of new compounds, is dependent, in the higher animals at least, on the connection of these tissues with the central nerve system; for if the efferent nerves be divided, not only will they undergo degeneration in their peripheral portions, but the muscles, glands, and connective tissues to which they are distributed will also undergo similar changes. This is to be attributed not merely to inactivity, but rather to a loss of nerve influence, inasmuch as inactivity leads merely to atrophy and not to degeneration. It would appear from facts of this character that the normal metabolism is dependent for its continuance on nerve influences. There is no evidence, however, as to the existence of special trophic nerves, separate from those which impart to glands and muscles their customary activities. The trophic centers and the motor centers are identical, though the two modes of their activity are separate and distinct.

Vascular Tonus.—The state of moderate contraction of the arterioles throughout the body, in consequence of which the average arterial pressure is maintained, has been attributed to constant activity of the vaso-motor centers, this activity being conditioned by variations in the composition of blood, either an increase in the quantity of carbon dioxid or a decrease in the quantity of oxygen. The vaso-motor centers are regarded as primarily automatic, though capable of being influenced secondarily by reflected excitations from the periphery or direct excitations from the cerebrum.

Muscle Tonus.—It is well known that if a muscle be divided in the living animal the two portions will contract and separate themselves to a certain distance. This indicates that the muscle when in a state of rest is in a slight degree of contraction. This condition of the muscle, to which the term muscle tonus is given, was formerly attributed to an automatic and continuous discharge of energy from the nerve-cells. Brondgeest, however, showed that this tonus is entirely reflex in origin and immediately disappears on division of the posterior roots of the spinal nerves, which would not be the case if the cells in the cord were acting automatically. The afferent nerves in this reflex arise in the muscle or its tendons, and the stimulus is the slight degree of extension to which the muscle is subjected in virtue of its attachments and the ever-varying position of the limbs and trunk.

The tonic contraction of the visceral muscles—*e. g.*, the pyloric, the vesical, the anal sphincters—though regarded as automatic by some, is probably reflex in origin, dependent on the arrival of afferent impulses from the periphery. It is probable that future investigation will disclose the existence and pathway of these afferent fibers.

Reflex Actions.—It has already been stated that the nerve-cells in the spinal cord are capable of receiving and transforming afferent nerve impulses, the result of peripheral stimulation into efferent nerve impulses, which are transmitted outward to muscles, exciting contraction; to glands, provoking secretion; to blood-vessels, changing their caliber; and to organs, inhibiting or accelerating their activity. All such actions taking place through the spinal cord and medulla oblongata independently of sensation or volition are termed reflex actions. The mechanism involved in every reflex action consists of at least the following structures (Fig. 232):

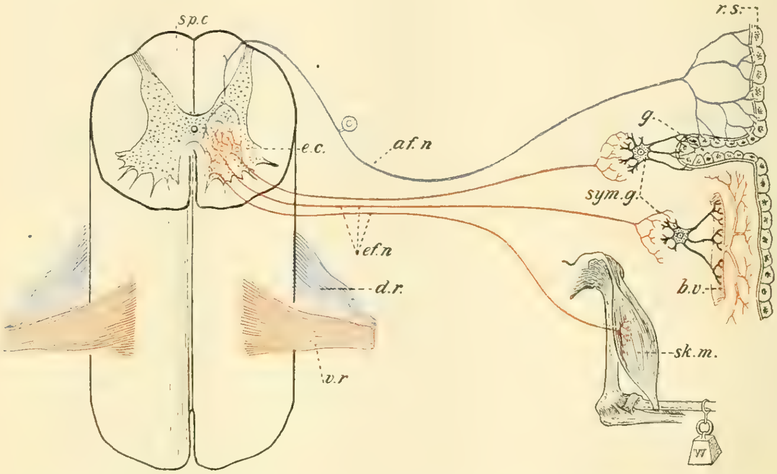

FIG. 232.—DIAGRAM SHOWING THE STRUCTURES INVOLVED IN THE PRODUCTION OF REFLEX ACTIONS, *G. Bachman.* *r.s.* Receptive surface; *af.n.* afferent nerve; *e.c.* emissive or motor cells in the anterior horn of the gray matter of the spinal cord, *sp.c.;* *ef.n.* efferent nerves distributed to responsive organs, *e. g.*, directly to skeletal muscles, *sk.m.*, and indirectly through the intermediation of sympathetic ganglia, *sym. g.*, to blood-vessels, *b.v.*, and to glands, *g.* The nerves distributed to viscera are not represented.

1. A receptive surface; *e. g.*, skin, mucous membrane, sense organ, etc.
2. An efferent fiber and cell.
3. An emissive cell, from which arises—
4. An efferent nerve, distributed to a responsive organ, as—
5. Muscle, gland, blood-vessel, etc.

In this connection the reflex contractions of skeletal muscles only will be considered.

If a stimulus of sufficient intensity be applied to the receptive surface, there will be developed in the terminals of the afferent nerve a series of nerve impulses which will be transmitted by the afferent nerve to, and received by, the dendrites of the emissive cell in the anterior horn of the gray matter. With the reception of these impulses there will be a disturbance in the equilibrium of the molecules of the cell, a liberation of energy and a transmission of nerve impulses outward through the efferent nerve to the muscle.

A reflex mechanism or arc of this simplicity would subserve but a simple movement. The majority of the reflexes, however, are extremely complex and involve the coöperation and coördination of a number of centers at different levels of the spinal cord and medulla, on the same and opposite sides, and of muscles situated at distances more or less remote from one another. The transference of nerve impulses coming from a localized area of a receptive surface, to emissive cells situated at different levels is accomplished by the intermediation of a third neuron situated in the gray matter which is in connection, on the one hand with the central terminals of the afferent nerve, and, on the other hand through collateral branches with the dendrites of the efferent neurons situated at different levels. (Fig. 233.) A histologic and physiologic mechanism of this character readily explains how a localized stimulation can give rise to reflex actions extremely complex in character.

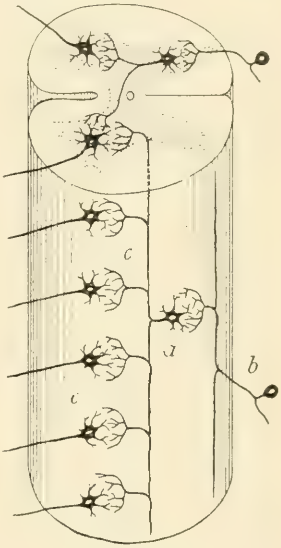

Fig. 233.—Diagram Showing the Relation of the Third Neuron *a*, to the Afferent Neuron *b*, and to the Efferent Neurons *c*, *c*, *c*.—(*After Kölliker.*)

The reflex contractions of skeletal muscles are best studied after division of the central nerve system at the upper limit of the spinal cord. After this procedure the spinal centers can act independently of, and uninfluenced by either sensation or volitional efforts on the part of the animal. Though it is possible to provoke reflex contractions under such circumstances in warm-blooded animals, they are, as a rule, incomplete and of short duration, owing to disturbances of the circulation and respiration and the consequent loss of tissue irritability. In frogs and in cold-blooded animals generally, the spinal cord retains its irritability for a long period of time after removal of the brain, and therefore is well adapted for the study of reflex actions.

The separation of the spinal cord from the brain is readily effected by destroying the medulla oblongata. This can be done by inserting a pin through the skin, the occipito-atlantal membrane covering the space between the occipital bone and the atlas, until it strikes the bodies of the vertebræ below. If the pin is properly directed it passes through the medulla. Care should be taken to avoid injury to the blood-vessels on either side. The brain itself should then be destroyed, so as to remove all consciousness, by inserting the pin into the brain cavity through the foramen magnum, and giving it a few rotatory movements.

A frog so prepared, and placed on the table and allowed to remain at rest for a few moments until the shock of the operation passes away, will draw the limbs close to the body and assume a position not unlike that of a normal frog. If then the posterior limbs be extended, they will immediately be drawn close to the side of the trunk in the usual flexed position. If the toes are pinched with forceps, the foot will execute a series of movements as if it were trying to free itself from the source of irritation.

If the frog be suspended, the limbs, through the force of gravity, will be gradually extended and hang down freely. In this, as in the sitting position, the animal will remain perfectly quiet and will not exhibit spontaneous movements. Any stimulus applied to the skin, however, provided it is of sufficient intensity, will be followed by a more or less pronounced movement. Mechanic, chemic and electric stimuli applied to any part of the skin will call forth the characteristic reflex movements. Chemic stimuli such as weak solutions of sulphuric or acetic acid placed on the toes will be followed by feeble flexion of the corresponding leg, to be succeeded in a short time by extension. Stronger solutions will produce more extensive and vigorous movements, the foot at the same time being rubbed against the thigh, apparently for the purpose of freeing it from the irritant. Similar phenomena follow the application of the acid to the fingers or the trunk. As a rule, the extent and complexity of the movement is within limits proportional to the strength of the stimulus. By limiting the sphere of action of the stimulus to definite but different areas of the skin a great variety of movements, more or less complex and coördinated and apparently purposive and defensive in character, can be produced. The coördinated and purposive character of the movements exhibited by a brainless frog led Pflüger to the assumption that the spinal cord in this as well as in other cold-blooded animals is possessed of sensorial functions, and endowed with rudimentary consciousness. This view, however, is not generally accepted, the movement being attributed to specialized mechanisms in the cord, partially inherited, which permit of one and the same movement with mechanic regularity and precision, so long as the conditions of the experiment remain the same.

In warm-blooded animals similar results may be obtained for a short time after division of the cord, especially if artificial respiration is maintained and the circulation of the blood continued. The cord will then retain its irritability for some time. If the conditions of experimentation were favorable, it is highly probable that the human spinal cord would execute similar movements. Thus it was observed by Robin in a man who had been decapitated that reflex muscle contractions could be elicited by stimulating the skin after the lapse of an hour after execution. "While the right arm was lying extended by the side, with the hand about 25 centimeters distant from the upper part of the thigh, I scratched with the point of a scalpel the skin of the chest at the areola of the nipple, for a space of 10 or 11 centimeters in extent, without making any pressure on the subjacent muscles. We immediately saw a rapid and successive contraction of the great pectoral muscle, the biceps, probably the brachialis anticus, and lastly the muscles covering the internal condyle. The result was a movement by which the whole arm was made to approach the trunk; with rotation inward and half-flexion of the forearm upon the arm; a true defensive movement, which brought the hand toward the chest as far as the pit of the stomach. Neither the thumb, which was partially bent toward the palm of the hand, nor the fingers, which were half bent over the thumb, presented any movements. The arm being replaced in its former position, we saw it again execute a similar movement on scratching the skin, in the same manner as before, a little below the clavicle. This experiment succeeded four times, but each time the movement was less extensive; and at last scratching the skin over the chest produced only contractions in the great pectoral muscle which hardly stirred the limb" (Dalton).

Laws of Reflex Action (Pflüger).

1. *Law of Unilaterality.*—If a feeble irritation be applied to one or more sensory nerves, movement takes place usually on one side only, and that the same side as the irritation.
2. *Law of Symmetry.*—If the irritation becomes sufficiently intense, motor reaction is manifested, in addition, in corresponding muscles of the opposite side of the body.
3. *Law of Intensity.*—Reflex movements are usually more intense on the side of irritation; at times the movements of the opposite side equal them in intensity; but they are usually less pronounced.
4. *Law of Radiation.*—If the excitation still continues to increase, it is propagated upward, and motor reaction takes place through centrifugal nerves coming from segments of the cord higher up.
5. *Law of Generalization.*—When the irritation becomes very intense, it is propagated in the medulla oblongata; motor reaction then becomes general, and it is propagated up and down the cord, so that all the muscles of the body are thrown into action, the medulla oblongata acting as a focus whence radiate all reflex movements.

Special Reflex Movements.—Among the reflexes connected with the more superficial portions of the body there are some which are so frequently either increased or diminished in pathologic conditions of the spinal cord that their study affords valuable indications as to the seat and character of the lesions. They may be divided into:

1. The skin or superficial, and
2. The tendon or deep reflexes.
3. The organ reflexes.

The skin reflexes, characterized by contraction of underlying muscles, are induced by stimulation of the skin—*e. g.*, pricking, pinching, scratching, etc. The following are the principal skin reflexes:

1. *Plantar reflexe*, consisting of contraction of the muscles of the foot, induced by stimulation of the sole of the foot; it involves the integrity of the reflex arc through the lower end of the cord.
2. *Gluteal reflex*, consisting of contraction of the glutei muscles when the skin over the buttock is stimulated; it takes place through the segments giving origin to the fourth and fifth lumbar nerves.
3. *Cremasteric reflex*, consisting of a contraction of the cremaster muscle and a retraction of the testicle toward the abdominal ring when the skin on the inner side of the thigh is stimulated; it depends upon the integrity of the segments giving origin to the first and second lumbar nerves.
4. *Abdominal reflex*, consisting of a contraction of the abdominal muscles when the skin upon the side of the abdomen is gently scratched; its production requires the integrity of the spinal segments from the eighth to the twelfth dorsal nerves.
5. *Epigastric reflex*, consisting of a slight muscular contraction in the neighborhood of the epigastrium when the skin between the fourth and sixth ribs is stimulated; it requires the integrity of the cord between the fourth and seventh dorsal nerves.
6. *Scapular reflex* consisting of a contraction of the scapular muscles when the skin between the scapulæ is stimulated; it depends upon the integrity of the cord between the fifth cervical and third dorsal nerves.

The skin or superficial reflexes, though variable, are generally present in health. They are increased or exaggerated when the gray matter of the cord is abnormally excited, as in tetanus, strychnin-poisoning, and disease of the lateral columns.

The so-called "*tendon reflexes*," characterized by the contraction of a muscle, are also of much value in the diagnosis of lesions of the cord and are elicited by a sharp tap on a given tendon. The term, tendon reflex, is, however, somewhat inaccurate. The fundamental condition for the production of the tendon reflex is the normal tone of the muscle, which is a true reflex, maintained by afferent nerve impulses developed in the muscle itself in consequence of its extension and hence compression of the end-organs of the afferent nerves, the muscle spindles. When the muscle is passively extended, as it is when the reflex is to be elicited, there is an exaltation of the tonus and an increase in the irritability. To this condition of the muscle due to passive tension, the term myotatic irritability has been given. If the muscle extension be now suddenly increased, as it is when the tendon is sharply tapped, the increased compression of the muscle spindles will develop additional afferent impulses which after transmission to the spinal cord will give rise to contraction of the corresponding muscle.

The following are the principal forms of the tendon reflexes:

1. *Patellar reflex or knee-jerk*, consisting of a contraction of the extensor muscles of the thigh when the ligamentum patellæ is struck between the patella and tibia. This reflex is best observed when the legs are freely hanging over the edge of a table. The patella reflex is generally present in health, being absent in only 2 per cent.; it is greatly exaggerated in lateral sclerosis, in descending degeneration of the cord; it is absent in locomotor ataxia and in atrophic lesions of the anterior gray cornua.
2. *Ankle-jerk or Ankle Reflex.*—If the extensor muscles of the leg be placed on the stretch and the tendo Achillis be sharply struck, a quick extension of the foot will take place.
3. *Ankle Clonus.*—This consists of a series of rhythmic reflex contractions of the gastrocnemius muscle, varying in frequency from six to ten per second. To elicit this reflex, pressure is made upon the sole of the foot so as to suddenly and energetically flex the foot at the ankle, thus putting the tendo Achillis and the gastrocnemius muscle upon the stretch. The rhythmic movements thus produced continue so long as the tension within limits is maintained. Ankle clonus is never present in health, but is very marked in lateral sclerosis of the cord.

The *toe reflex*, *peroneal reflex*, and *wrist reflex* are also present in sclerosis of the lateral columns and in the late rigidity of hemiplegia.

The organ reflexes, *e. g.*, the activities of the genito-urinary organs, the stomach, intestines, gall-bladder, etc., and which are induced by peripheral stimulation have been considered in connection with the physiologic action of these organs. The genito-urinary center is located in the lumbar region of the spinal cord. In diseased conditions of this region the genito-urinary reflexes are sometimes increased, at other times decreased or even abolished.

Reflex Irritability.—The general irritability or quickness of response of the mechanism involved in reflex action can be approximately determined by observation of the length of time that elapses between the application of a minimal stimulus and the appearance of the muscle response. The method of Türck is sufficiently accurate for general purposes. This consists in suspending a frog, after removal of the brain, and immersing the foot in a 0.2 per cent. solution of sulphuric acid. The time is determined by means of a metronome beating one hundred times a minute. Stimulation of the skin can also be effected by the induced electric current, as suggested by Gaskell. A single shock is, however, ineffective. When the shocks follow each other with sufficient rapidity, they give rise to a summation of effects in the nerve-centers which will soon be followed by a muscle response. It is highly probable that the chemic stimulation gives rise to a similar summation of effects.

The period of time thus obtained is distributed over the entire mechanism. The true reflex time, however—*i. e.*, the time occupied in the passage of the nerve impulses across the spinal mechanism—

is shorter and is obtained by subtracting from the whole period the time occupied by the passage of the impulses through the afferent and efferent nerves as well as the latent period of muscle contraction. This corrected period, the true reflex time, has been found to be twelve times longer than the time occupied by the passage of the nerve impulse through the nerves, including the latent period of the muscle.

The reflex irritability is increased by:

1. *Separation of the Brain from the Cord.*—This is at once followed by an increase in reflex irritability, and is taken as evidence that the brain normally exerts an inhibitor influence over the reflex centers of the cord. The same increase is observed upon hemisection of the cord, though the increase is limited to the same side.
2. *The Toxic Action of Drugs.*—Strychnin even in small doses increases the irritability to such an extent that a minimal stimulus is sufficient to call forth spasmodic contractions of all the skeletal muscles. Under its influence the usual coördinated reflexes disappear and are succeeded by incoördinated reflexes. The explanation of this fact is believed to be a diminution in the resistance offered by the cord to the passage of the afferent impulses rather than to a direct stimulation of the efferent cells. So much is this resistance decreased that the nerve impulses, instead of being confined to their accustomed paths, are radiated in all directions. Absolute repose of the animal and the exclusion of all external stimuli greatly diminish the tendency to the occurrence of spasms.
3. *Degeneration of the Pyramidal Tracts.*—In primary lateral sclerosis, a pathologic condition characterized primarily by a degeneration of the terminal filaments of the pyramidal tract fibers, the reflex activity of the cord becomes exalted. As the disease progresses the irritability increases to such an extent that violent spasmodic contractions of the arms and legs arise when the skin or tendons are mechanically stimulated. The explanation offered is practically the same as in division of the cord: viz., withdrawal of the inhibitor and controlling influence of the brain.

The reflex excitability may be decreased by:

1. *Stimulation of Certain Regions of the Brain.*—It was discovered by Setchenow that when the frog brain is divided just anterior to the optic lobes and the reflex time subsequently determined according to the method of Türck, that the time can be considerably lengthened by stimulation of the optic lobes. This is readily accomplished by placing small crystals of sodium chlorid on the optic lobes. It was concluded from this fact that these lobes contain centers which exert an inhibitor influence over centers in the spinal cord through descending nerve-fibers. This

conclusion is strengthened by the fact that division of the brain just behind the optic lobes causes a temporary inhibition of the reflexes in consequence of a mechanical irritation of these fibers. It is quite probable that the volitional inhibition of certain reflexes is accomplished through the intermediation of this center localized by Setchenow. (Fig. 234.)

2. *Stimulation of Sensor Nerves.*—If during the application of a stimulus sufficient to call forth a characteristic reaction in a definite period of time, a sensor nerve in a distant region of the body be simultaneously stimulated, it will be found that the reflex time will be lengthened or the reaction completely inhibited.
3. *Lesions of the spinal cord; e. g.*, atrophy of the multipolar cells of the anterior horns of the gray matter; degeneration of the terminals of the dorsal root fibers.
4. *The toxic action* of various drugs —*e. g.*, chloroform, chloral— which are believed to exert a depressing action on the nerve-cells themselves.

The Spinal Cord as a Conductor.—The white matter of the spinal cord consists of nerve-fibers the specific function of which is

1. To conduct nerve impulses from one segment of the cord to another.
2. To conduct nerve impulses coming to the cord through afferent nerves, directly or indirectly to various areas of the encephalon.
3. To conduct nerve impulses from the encephalon to the spinal cord segments.

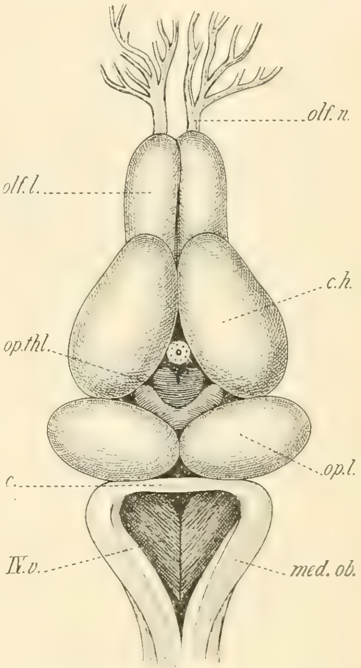

FIG. 234.—DIAGRAM OF THE BRAIN OF THE FROG. *olf. n.* olfactory nerves; *olf. l.* olfactory lobes; *c. h.* cerebral hemispheres; *op. thl.* optic thalamus; *op. l.* optic lobes; *c.* cerebellum; *med. of.* medulla oblongata; *IV. v.* fourth ventricle.

Intersegmental or Associative Conduction.—The spinal cord consists of a series of physiologic segments each of which has specific functions and is associated through its related spinal nerve with a definite segment of the body. For the harmonious coöperation and coördination of all the spinal segments it is essential that they should be united by commissural or associative fibers. This is, in fact, accomplished by the axons of the intrinsic cells of the gray matter, which constitute such a large part of the antero-lateral and posterior root zones. In consequence of this association, the cord becomes capable of complex coördinated and purposive reflex actions.

Spino-encephalic or Sensor Conduction.—The nerve impulses that arise in consequence of impressions made on the terminals of the nerves in the cutaneous and mucous surfaces, in the viscera and in the muscles, are transmitted through the dorsal roots of the spinal nerves to the cord. When transmitted through the cord to the cerebral hemispheres directly or indirectly, they are received by specialized nerve-cells in the cortex and translated into conscious sensations. The sensations thus arising may be divided into special and general sensations. Of the former may be mentioned pain, touch, pressure, temperature; of the latter may be mentioned hunger, thirst, fatigue, well-being, etc.

The pathways through the spinal cord that conduct these afferent impulses to the brain are ill defined and imperfectly known, and only for a few sensations can it be said that their pathways have been determined. The reason for this obscurity lies partly in the difficulties of experimentation, partly in the difficulties of interpretation. Clinical observations are for special reasons more or less untrustworthy.

Section of one lateral half of the cord, or a lesion involving the one lateral half, as a rule abolishes all forms of cutaneous sensibility on the opposite side below the injury. This would seem to prove that the nerve impulses cross the median line of the cord immediately or very shortly after entering. At the same time, muscle sensibility is abolished on the corresponding side below the injury. This would seem to prove that the fibers of the posterior roots which enter and cross the column of Burdach and ascend in the column of Goll are derived mainly from the muscles. It is, however, believed by some investigators that those fibers which subserve the sense of touch do not decussate at once, but ascend in the column of Goll as far as the medulla oblongata, where they, in common with the fibers coming from the muscles, arborize around the nerve-cells in the gracile and cuneate nuclei. The afferent path is then continued by new nerve-fibers which emerge from these cells, and which, after crossing the median plane and decussating with the fibers coming from the opposite side, join the afferent path from the spinal cord. These fibers are known as the internal arcuate fibers and assist in the formation of the lemniscus or fillet. (Fig. 235.) The sensor pathway decussates in part at different levels of the spinal cord and in part at the level of the gracile and cuneate nuclei. The former is often termed the lower, the latter the upper sensor decussation.

The pathways for the impulses that give rise to the different sensation have been variously located by different observers, *e. g.*, in the gray matter, in the limiting layer, and in the antero-lateral tract of Gowers; the pathway for the impulses that give rise to temperature sensations has been located in the gray matter; the pathway for tactile impressions has been located in the posterior columns, though this is not beyond dispute. The pathway for pain sensations has been located in Gowers' tract.

Encephalo-spinal or Motor Conduction.—At birth the child is capable of performing all the functions of organic life, such as sucking, swallowing, breathing, etc. It is, however, deficient in psychic activity and in volitional control of its muscles. Its movements are therefore largely, if not entirely, reflex in character.

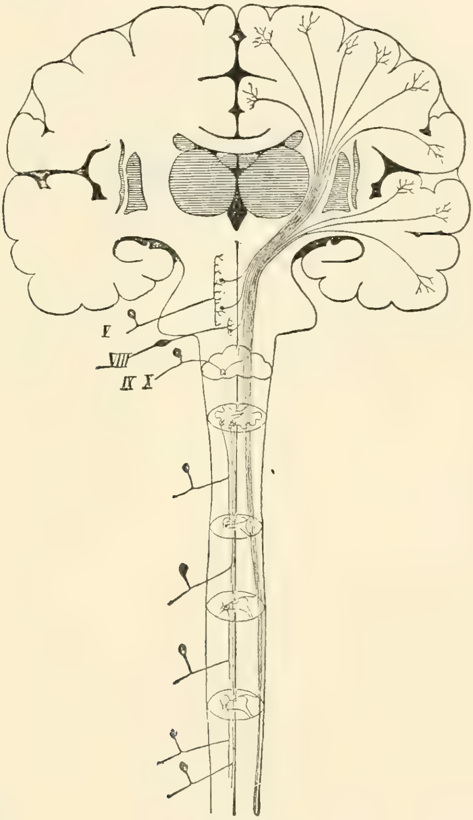

Fig. 235.—Diagram of the Sensor Pathways in the Spinal Cord Augmented above by Fibers of the Sensor Cranial Nerves and Nerves of Special Sense. V. The trifacial nerve. VIII. The vestibular branch of the acoustic nerve. IX. The glosso-pharyngeal nerve. X. The pneumogastric nerve.—(*Van Gehuchten.*)

Embryologic and histologic examination of the spinal cord and medulla show that so far as their mechanisms for independent physiologic activities are concerned both are fully developed. Similar investigations of the cerebral hemispheres and of the nerve-fibers which bring their nerve-cells into relation with the spinal segments show that the cells of the cortex are not only immature, but that their descending axons are incompletely invested with myelin. With the growth of the child, psychic life unfolds and volitional control of muscles is acquired. Coincidently the cells of the cerebral cortex grow and develop and the fibers become covered with myelin.

The nerve-fibers which have their origin in the cells of the cerebral cortex, and which terminate in tufts around the cells in the anterior horns of the gray matter of the spinal segments, are to be regarded as long commissural tracts uniting and associating these two portions of the central nerve system.

Experimental investigations and observations of pathologic lesions accord with the view that physiologically these fibers are efferent pathways for the transmission of motor or volitional impulses from the cortex to the spinal segments. The nerve-cells in which the motor impulses originate are located for the most part, as will be fully stated later, in the central portion of the cortex of the cerebral hemispheres in the neighborhood of the central or Rolandic fissure. The axons of these cells from each hemisphere descend through the corona radiata to and through the internal capsule, along the inferior surface of the crura cerebri, behind the pons to the medulla, of which they constitute the anterior pyramids. (Fig. 236.) At this point the pyramidal tract* of each side divides into two portions, viz.:

1. A large portion, containing from 80 to 90 per cent. of the fibers, which decussates at the lower border of the medulla and passes downward in the posterior part of the lateral column of the opposite side, constituting the *crossed pyramidal tract;* as it descends it gradually diminishes in size as its fibers or their collaterals enter the gray matter of each successive segment.
2. A small portion, containing from 20 to 10 per cent. of the fibers, which does not decussate at the medulla but passes downward on the inner side of the anterior column of the same side, constituting the *direct pyramidal tract* or column of Türck. This tract can be traced down, as a rule, only as far as the mid-dorsal region. As it descends it becomes smaller as its fibers cross the anterior commissure to enter the gray matter of the opposite side. Thus all the fibers of the pyramidal tract from each cerebral hemisphere eventually are brought into relation with the cells of the gray matter of the opposite side of the cord.

That the pyramidal tracts are the conductors of volitional impulses throughout the length of the cord to its various segments has been made evident by the results of section, electric stimulation, and disease. Division of the anterior and lateral columns of one side of the cord in any part of its extent is invariably followed by a loss of motion or paralysis of the muscles below the section, while electric stimulation of the peripheral end of the isolated crossed pyramidal tract is followed by marked characteristic movements of the muscles. Similar results follow division of the pyramidal tract in any part of its course from

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* From the fact that the region included between the origin of these fibers and the internal capsule presents somewhat the form of a pyramid with four sides, Charcot designated it the pyramidal region and the fibers composing it the *pyramidal tract.* The base of the pyramid includes the cortex of the convolutions around the Rolandic fissure. The summit of the pyramid is truncated and covers the *pyramidal* region of the internal capsule.

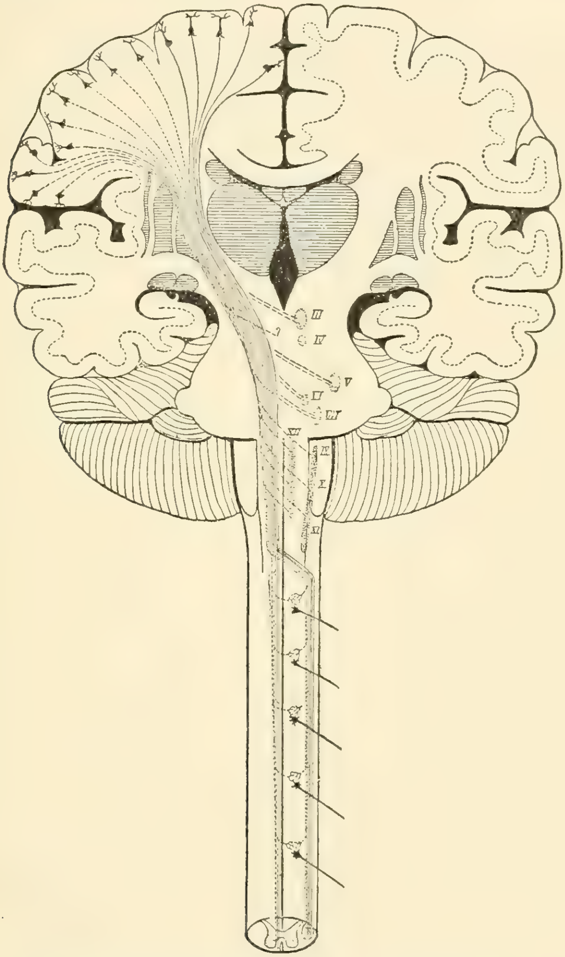

Fig. 236.—Diagram of the Pyramidal Tract or Motor Path. III. Common oculo-motor nerve. IV. Pathetic nerve. V. Motor division of the trigeminal nerve. VI. The abducens nerve. VII. Facial nerve. IX. and X. Motor divisions of the glosso-pharyngeal and pneumogastric nerves. XI. Spinal accessory nerve. XII. Hypoglossal nerve.—(*Van Gehuchten.*)

the cerebral cortex downward. Electric stimulation of the cortical cells which give origin to the pyramidal tract is also followed by contraction of the muscles of the opposite side, while their destruction is attended by paralysis of the same muscles. As the nutrition of the fibers is governed by the cells, it follows that when the axon is separated from its cell it degenerates. It has been found that a lesion of the pyramidal tract in any part of its course is followed by descending degeneration, which is taken in evidence that it conducts nerve impulses from above downward. Thus experimental investigation and pathologic observation are in accord in the view that physiologically these nerve-fibers are the pathways for the transmission of motor or volitional impulses from the encephalon to the spinal cord.

The relation of the motor and sensor pathways to each other in the spinal cord and brain are shown in Plate II. The afferent fibers which decussate at various levels through the spinal cord are not represented.

CHAPTER XX.

THE MEDULLA OBLONGATA; THE ISTHMUS OF THE ENCEPHALON; THE BASAL GANGLIA.

THE MEDULLA OBLONGATA.

The **medulla oblongata** is that portion of the central nerve system immediately superior to and continuous with the spinal cord. It has the shape of a truncated cone, the base of which is directed upward, the truncated apex downward. It is 38 mm. in length, 18 mm. in breadth, and 12 mm. in thickness. By the continuation upward of the anterior and posterior median fissures, the medulla is divided into symmetric halves (Figs. 237 and 238). Like the cord, of which it is a continuation, it is composed of white matter externally and gray matter internally.

Structure of the Gray Matter.—The gray matter of the medulla is continuous with that of the cord, though owing to the shifting of position of the different tracts of the white matter it is arranged with much less regularity. The appearance which the gray matter presents on transverse section varies also at different levels.

At the level of the first cervical nerve the posterior horns are narrow, elongated, and directed outward. The lateral horns are well developed and present a collection of cells near their bases which can be traced forward and backward for some distance. At the level of the decussation of the pyramidal tracts the head of the anterior horn becomes detached from the rest of the gray matter and is pushed backward toward the posterior horn; the bases of the anterior horns become spread out to form a layer of gray matter near the dorsal aspect of the medulla. Transverse sections of the medulla at all levels show a more or less extensive network of nerve-fibers known as the reticular formation. In its meshes are found collections of nerve-cells of varying size. Toward the dorsal aspect of the medulla special groups of cells are found from which axons arise to become the fibers of various efferent cranial nerves, *e. g.*, the hypoglossal, the efferent fibers of the vagus, and glossopharyngeal.

Structure of the White Matter.—The white matter is composed of nerve-fibers supported by connective tissue and neuroglia. It is subdivided on either side by grooves into three main columns: viz., an anterior column or pyramid, a lateral column, and a posterior column.

The *anterior column* or pyramid is composed partly of fibers continuous with those of the anterior column of the spinal cord (the direct pyramidal tract), and partly of fibers continuous with those of the lateral column of the cord of the opposite side (the crossed pyram-

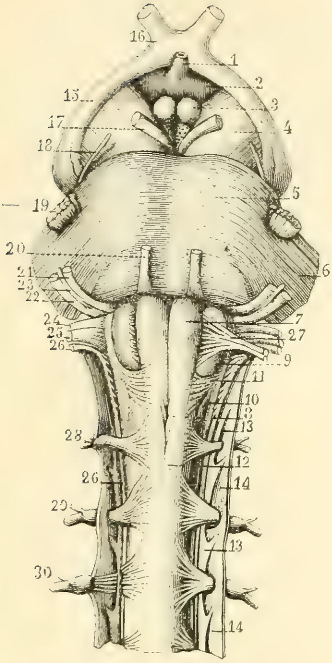

FIG. 237.—ANTERIOR OR VENTRAL VIEW OF THE MEDULLA OBLONGATA AND ISTHMUS. 1. Infundibulum. 2. Tuber cinereum. 3. Corpora albicantia. 4. Cerebral peduncle. 5. Tuber annulare. 6. Origin of the middle peduncle of the cerebellum. 7. Anterior pyramids of the medulla oblongata. 8. Decussation of the anterior pyramids. 9. Olivary bodies. 10. Restiform bodies. 11. Arciform fibers. 12. Upper extremity of the spinal cord. 13. Ligamentum denticulatum. 14, 14. Dura mater of the cord. 15. Optic tracts. 16. Chiasm of the optic nerves. 17. Motor oculi communis. 18. Patheticus. 19. Fifth nerve. 20. Motor oculi externus. 21. Facial nerve. 22. Auditory nerve. 23. Nerve of Wrisberg. 24. Glosso-pharyngeal nerve 25. Pneumogastric. 26, 26. Spinal accessory. 27. Sublingual nerve. 28, 29, 30. Cervical nerves.—(*Sappey.*)

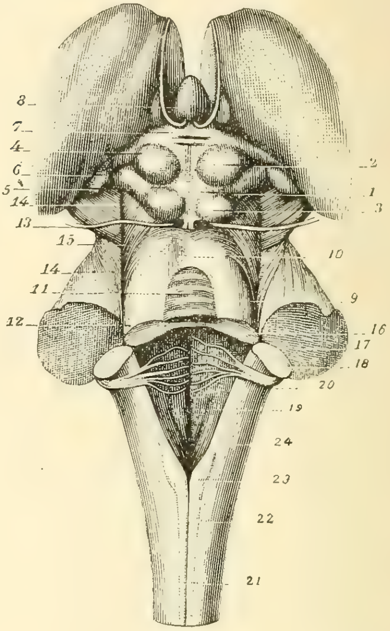

FIG. 238.—POSTERIOR OR DORSAL VIEW OF THE MEDULLA OBLONGATA, ISTHMUS, AND BASAL GANGLIA. 1. Corpora quadrigemina. 2. Corpus quadrigeminum anterior (pregeminum). 3. Corpus quadrigeminum posterior (post-geminum). 4. Tract of fibers (brachium) passing to the corpus geniculatum externum. 5. Tract of fibers (brachium) passing to 6, the corpus geniculatum internum. 7. Posterior commissure. 8. Pineal gland. 9. Superior cerebellar peduncle. 10, 11, 12. The valve of Vieussens. 13. The pathetic nerve. 14. Lateral groove of the isthmus. 15. Triangular bundle of the isthmus. 16. Superior cerebellar peduncle. 17. Middle cerebellar peduncle. 18. Inferior cerebellar peduncle. 19. Antero-inferior wall of the fourth ventricle. 20. Acoustic nerve. 21. Spinal cord. 22. The postero-median column. 23. The posterior pyramids.—(*Sappey.*)

idal tract), which decussate at the anterior portion of the medulla. The united fibers can be traced upward to the pons, where they disappear from view.

The *lateral column* is composed of fibers continuous with those of the lateral column of the cord. As the fibers pass upward, however, they diverge in several directions. The fibers of the crossed pyramidal tract cross the median line, as previously stated, to enter into the formation of the anterior column; the fibers of the direct cerebellar tract gradually curve backward, and in so doing unite with other fibers to form the restiform body, after which they enter the cerebellum by way of the inferior peduncle. Situated between the anterior pyramid and the restiform body is a small oval mass, the olivary body, composed of both white and gray matter.

The *posterior column* is composed largely of fibers continuous with those of the posterior column of the cord. The subdivision of this column into a postero-external (Burdach) and a postero-internal (Goll) is more marked in the medulla than in the cord. The former is here known as the *funiculus cuneatus*, the latter as the *funiculus gracilis*. These two strands of fibers are apparently continued into the restiform body. Owing to the divergence of the restiform bodies a V-shaped space is formed, the floor of which is covered with epithelium resting on the ependyma. At the upper extremity of the funiculus cuneatus and funiculus gracilis, two collections of gray matter are found, known respectively as the *nucleus cuneatus* and *nucleus gracilis*. Around the cells of these nuclei many of the fibers of the posterior column end in brush-like expansions.

The Fillet or Lemniscus.—From the ventral surface of the cuneate and gracile nuclei axons emerge which pass forward and upward through the gray matter and decussate with corresponding fibers coming from the opposite nuclei. They then assume a position just posterior to the pyramids and between the olivary bodies. These fibers thus form a new distinct tract, termed the fillet or lemniscus. As this tract ascends toward the brain it receives additional axons from the sensory end-nuclei of all the afferent cranial nerves of the opposite side with the exception of the auditory. From the end-nuclei of the auditory nerve new axons ascend as a distinct tract situated near the lateral aspect of the pons. From their position these two separate tracts have been termed the mesial and lateral fillets respectively.

Before proceeding to a consideration of the functions of the medulla oblongata it will be found conducive to clearness to sketch the salient anatomic features of the parts anterior to it and their relations one to another.

THE ISTHMUS OF THE ENCEPHALON.

The **isthmus of the encephalon** comprises that portion of the central nerve system connecting the cerebrum above, the cerebellum behind, and the medulla below. Its *ventral surface* presents below an enlargement, convex from side to side, the *pons Varolii.* On each side the fibers of which the pons consists converge to form a compact bundle, the middle peduncle, which enters the corresponding half of the cerebellum. Above the pons, this surface presents two large columns of white matter which, diverging somewhat from below upward, enter the base of the cerebrum and are known as the *crura cerebri.* Embracing the crura above are two large bands of white matter, the optic tracts (Fig. 237).

The *dorsal surface* presents below two diverging columns of white matter, the inferior peduncles; above, two converging columns, the superior peduncles of the cerebellum (Fig. 238). At the extreme upper part of this surface there are four small grayish eminences, the *corpora quadrigemina.* From the disposition of the white matter on the dorsal surface of the isthmus and medulla, there is formed a lozenge-shaped space, the *fourth ventricle.* The space is merely an expansion of the central cavity of the cord, the result of the changed relations of the white and gray matter in this region of the central nerve system. Above, this ventricle communicates by a narrow canal, the aqueduct of Sylvius, with the third ventricle. The floor of the fourth ventricle is covered with a layer of epithelium resting on the ependyma continuous with that lining the central canal of the cord. Beneath this is a layer of gray matter.

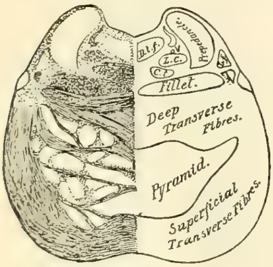

FIG. 239.—TRANSECTION OF THE PONS THROUGH ITS MIDDLE PORTION, SHOWING THE RELATION OF THE NERVE TRACTS OF WHICH IT IS COMPOSED. D. l. f. Dorsal longitudinal fasciculus. L.c. and c. Locus ceruleus. L.f. Lateral fillet.

The **pons Varolii** comprises in a general way that portion of the central nerve system situated between the medulla oblongata and the crura cerebri. The ventral surface is convex from side to side; the lateral surface, owing to the convergence of the fibers of which it is composed, is contracted to form the middle peduncle of the cerebellum; the posterior surface is flat and forms the upper half of the floor of the fourth ventricle. The pons consists of white fibers and gray matter supported by connective tissue and neuroglia. Transverse sections of the pons show that it is divided into an *anterior* or *ventral,* and a *posterior* or *dorsal portion,* the latter being usually termed the tegmentum.

The *ventral portion* consists for the most part of white fibers, arranged longitudinally and transversely (Fig. 239). The longitudinal fibers are largely continuations of the pyramidal tracts, or the fibers composing the anterior pyramid of the medulla. In the lower part of the pons these fibers are compactly arranged, but at higher levels they are separated into a number of bundles by the interlacing of the transverse fibers. The transverse fibers are divided into a superficial and a deep set. Among these fibers are groups of nerve-cells which collectively are known as the *nucleus pontis*. Some of the transverse fibers, especially the superficial ones, are commissural in character—*i. e.*, they connect corresponding parts of the gray matter of the lateral halves of the cerebellum; others coming from the gray matter of the cerebellum cross the median line and terminate around the cells of the nucleus pontis; others again are connected with the gray cells of the same side. Through the intermediation of the nucleus pontis and certain of the longitudinal fibers of the pons, the cerebellum is brought into relation with the cerebrum.

The *dorsal* or *tegmental portion* consists of: (1) The fillet; (2) the formatio reticularis; (3) the posterior longitudinal bundle; (4) the substantia ferruginosa; (5) groups of nerve-cells from which arise various cranial nerves—*e. g.*, the fifth, sixth, seventh, and eighth.

The *fillet* or *lemniscus* in this region is divided into a mesial and a lateral portion. The fibers of the *mesial portion* are partly the axons of the nerve-cells of the gracile and cuneate nuclei of the opposite side of the medulla, and partly of the axons of the sensor nerve-cells of the afferent cranial nerves with the exception of the auditory. The fibers of the *lateral portion* are mainly the axons of the cells in the floor of the fourth ventricle around which the auditory nerve-fibers end. They are therefore a continuation of the auditory tract.

The *formatio reticularis* is a continuation of that of the medulla.

The *posterior longitudinal bundle* is triangular in shape and situated behind the formatio reticularis and close to the median line. The fibers composing it are largely derived from the ground fibers of the antero-lateral column of the spinal cord.

The *superior olive* is a cylindric mass of gray matter situated in the pons in the anterior part of the formatio reticularis. It consists of nerve-cells the axons of which pass dorso-laterally, decussate in the median line, and form the lateral fillet of the opposite side. Some few axons go to the lateral fillet of the same side.

The *substantia ferruginosa* is composed mainly of pigmented cells.

The groups of nerve-cells lying just beneath the floor of the fourth ventricle give origin to axons of the motor portion of the fifth, the sixth, the seventh cranial nerves. Some of the groups are the sensor end-nuclei of the fifth and eighth cranial nerves.

The **crura cerebri** comprise that portion of the central nerve system situated between the pons below and the cerebrum above. They are composed of strands of nerve-fibers which are divided, as shown on cross-section, into a *ventral* and a *dorsal* portion by a crescentic shaped layer of gray matter, the substantia nigra (Fig. 240). Of the fibers which compose the *ventral portion* of each crus, the *crusta or pes*, the larger part is continuous below, through the longitudinal fibers of the pons, with the pyramid of the medulla and the pyramidal tract; above they assist in the formation of the internal capsule. On the inner and on the outer side of each crusta there is a bundle of fibers derived from the frontal, and from the temporal and occipital portions of the cerebrum respectively. These fibers are connected directly with the nuclei pontis and indirectly with the cerebellum of the same and opposite sides. The fibers which compose the *dorsal portion*, the *tegmentum*, are continuous with those which pass upward from the medulla and pons, *e. g.*, the fillet, both mesial and lateral, the formatio reticularis, the posterior longitudinal bundle, and, in addition, the fibers of the superior peduncles of the cerebellum. Above, the fibers terminate largely in collections of gray matter at the base of the cerebrum.

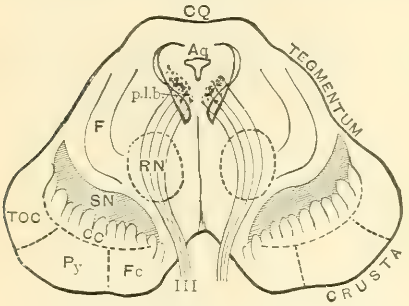

FIG. 240.—SCHEME OF TRANSVERSE SECTION OF THE CEREBRAL PEDUNCLES. CQ. Corpora quadrigemina. Aq. Aqueduct. p.l.b. Posterior longitudinal bundle. F. Fillet or lemniscus. RN. Red nucleus. SN. Substantia nigra. III. Third nerve. Py. Pyramidal tracts. Fc. Fronto-cerebellar; and TOC, temporo-occipital fibers of the crusta. CC. Caudate-cerebellar fibers in upper part of crusta.—(*After Wernicke and Gowers.*)

The *aqueduct of Sylvius* is a short narrow canal which connects the cavity of the fourth with the cavity of the third ventricle. It is lined by the ependyma and surrounded by a layer of gray matter continuous with that forming the floor of the fourth ventricle. In that portion of the gray matter lying beneath or ventral to the aqueduct there are groups of nerve-cells which give origin to axons which unite to form the third and fourth cranial nerves.

THE CORPORA QUADRIGEMINA.

The **corpora quadrigemina** are four small grayish eminences situated beneath the posterior border of the corpus callosum and behind the third ventricle. They rest upon the lamina quadrigemina, which forms the roof of the aqueduct of Sylvius. The anterior pair are termed the nates, or the *pregemina*, the posterior pair the testes, or the *postgemina*.

From the external surface of each body there pass outward bundles of fibers termed *brachia*. The fibers which compose the brachium of the pregeminum pass outward and enter a small collection of gray matter, the *corpus geniculatum externum*, and the optic tract. The fibers which compose the brachium of the postgeminum are divided into two bundles, one of which enters a second small collection of gray matter, the *corpus geniculatum internum*, while the other passes forward beneath this body to enter the internal capsule, beyond which it passes to the cortex of the temporal region of the cerebrum.

Though these bodies are closely associated anatomically, they differ in origin, in their relations and in their functions.

Microscopic examination of sections of the quadrigeminal bodies shows that they are composed of nerve-cells and nerve-fibers, both of which are so intricately arranged that it is difficult to trace their relation one to another and to adjoining structures. Some of the cells of the pregeminum give off axons which course outward and forward, enter the internal capsule, and pass through the optic radiation to the cortex of the occipital region of the cerebrum. Many fibers of the optic tract, axons of the cells of the retina, end in brush-like expansions around these same cells. There is thus formed a connected pathway between the retina and the occipital cortex.

The cells of the occipital cortex, however, send axon fibers in the reverse direction through the optic radiation to terminate around the cells of the pregeminum, while axons of pregeminal cells pass forward to the retina and to the cells of origin of the third nerve.

The cells of the postgeminum give origin to axons which pass upward, forward, and outward, enter the internal capsule, and pass by way of the auditory tract to the cortex of the temporo-sphenoidal region of the cerebrum. Many of the fibers of the lateral fillet, a portion of the auditory tract, terminate in brush-like expansions around these same cells. There is thus established a connected pathway between the cochlea and the temporo-sphenoidal cortex. The cells of the temporal cortex, however, send axons in the reverse direction by way of the auditory tract to the cells of the postgeminum. There is thus established a double communication between the occipital and temporal region of the cerebral cortex, and the pregeminal and postgeminal bodies respectively.

THE BASAL GANGLIA; THE CORPORA STRIATA AND OPTIC THALAMI.

The **basal ganglia** surmount the crura cerebri, but are only made visible by removal of the cerebrum (Fig. 241).

The **corpora striata** are two large ovoid collections of gray and white matter situated at the base of the cerebrum. The larger portion of each body is embedded in the cerebral white matter, while the smaller portion projects into the anterior part of the lateral ventricle. A transection of the corpus striatum shows that it is divided by a band of white matter into two portions, viz.:

1. The *caudate nucleus*, the intra-ventricular portion, convex in shape with its base directed forward, its apex or tail directed backward and downward.
2. The *lenticular nucleus*, the extra-ventricular portion, somewhat biconvex in shape and embedded largely in the white matter. Each lenticular nucleus is subdivided by two lamina of white matter into three portions. The two inner, from their pale yellow color, form the *globus pallidus*, the outer, somewhat darker in color, is the *putamen*.

The Internal Capsule.—The band of white matter separating the caudate from the lenticular nucleus has been termed the internal capsule from the manner in which it embraces the inner surface of the lenticular nucleus. It consists of nerve-fibers which associate histologically and physiologically all portions of the cerebral cortex with the optic thalamus, pons, medulla, spinal cord, and cerebellum. The relation of the capsule to the nuclei through which it passes is readily

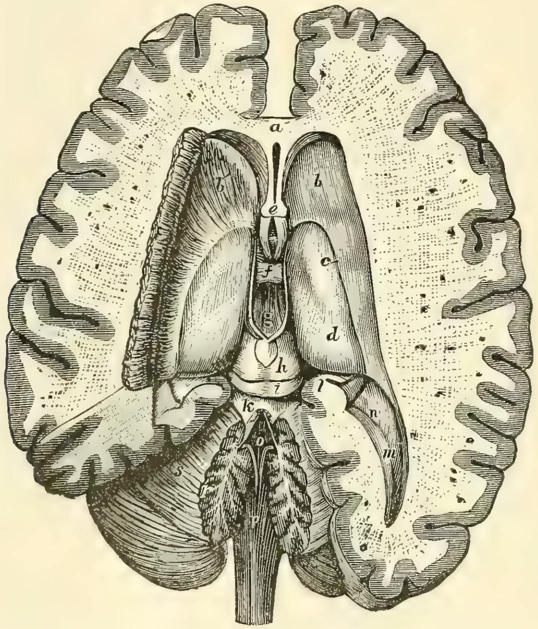

Fig. 241.—Dissection of Brain, from above, Exposing the Lateral Fourth and Fifth Ventricles with the Surrounding Parts. ½.—*a*. Anterior part, or genu of corpus callosum. *b*. Corpus striatum. *b'*. The corpus striatum of left side, dissected so as to expose its gray substance. *c*. Points by a line to the tænia semicircularis. *d*. Optic thalamus. *e*. Anterior pillars of fornix divided; below they are seen descending in front of the third ventricle, and between them is seen part of the anterior commissure; in front of the letter *e* is seen the slit-like fifth ventricle, between the two laminæ of the septum lucidum. *f*. Soft or middle commissure; *g* is placed in the posterior part of the third ventricle; immediately behind the latter are the posterior commissure (just visible) and the pineal gland, the two crura of which extend forward along the inner and upper margins of the optic thalami. *h*. and *i*. The corpora quadrigemina. *k*. Superior crus of cerebellum. Close to *k* is the valve of Vieussens, which has been divided so as to expose the fourth ventricle. *l*. Hippocampus major and corpus fimbriatum, or tænia hippocampi. *m*. Hippocampus minor. *n*. Eminentia collateralis. *o*. Fourth ventricle. *p*. Posterior surface of medulla oblongata. *r*. Section of cerebellum. *s*. Upper part of left hemisphere of cerebellum exposed by the removal of part of the posterior cerebral lobe.—(*Hirschfeld and Leveillé.*)

shown on cross-section (Fig. 242). The appearance which it presents, however, varies considerably at different levels. At a given level it may be said to consist of two segments or limbs, an *anterior*, situated between the caudate nucleus and the anterior extremity of the lenticular nucleus, and a *posterior*, situated between the optic thalamus and the posterior extremity of the lenticular nucleus. The two segments unite at an obtuse angle, termed the knee, which is directed toward the median line.

The **optic thalami** are two oblong masses of gray matter situated upon the crura cerebri and behind the corpora striata. The anterior and posterior extremities of each thalamus present enlargements known respectively as the anterior tubercle and the posterior tubercle or *pulvinar.* The mesial surface of the thalamus forms the lateral wall of the third ventricle and is covered by epithelium resting on a thin layer of ependyma.

A transection of the thalamus shows that it is not only covered externally but penetrated by white matter, which subdivides its contained gray cells into four more or less distinct masses termed nuclei, viz., an *anterior,* a *lateral,* occupying the external part of the thalamus, a *ventral,* close to the entire ventral surface, and a *posterior,* situated beneath the pulvinar. Beneath and somewhat internal to each optic thalamus there is a region, the subthalamic, consisting of an intricate network of nerve-fibers and several nuclei of gray matter, *e. g.,* the red or tegmental nucleus, the subthalamic nucleus, or Luys' body, and the substantia nigra.

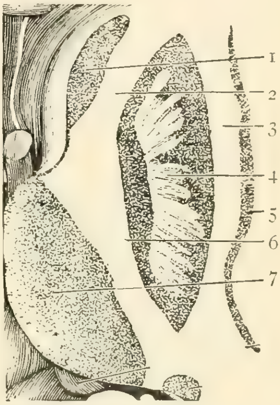

FIG. 242.—HORIZONTAL SECTION OF THE INTERNAL CAPSULE SHOWING ITS RELATIONS TO THE CAUDATE NUCLEUS, OPTIC THALAMUS, AND THE LENTICULAR NUCLEUS. 1. Caudate nucleus. 2. *Anterior segment of the internal capsule.* 3. External capsule. 4. Lenticular nucleus. 5. Claustrum. 6. *Posterior segment of internal capsule.* 7. Optic thalamus.—(*Modified from Landois.*)

Though the thalamus has extensive connections with many portions of the central nerve system, the most important are with the cortex, the tegmentum, and the optic tracts.

From the cells of these various nuclei axons emerge which pass into the internal capsule, and through the corona radiata to all portions of the cortex. Those which come from the pulvinar and pass to the occipital lobe constitute a part of the optic radiation; those from the lateral and ventral nuclei ultimately reach the parietal lobe; those from the anterior nucleus pass to the hippocampal and uncinate convolutions. In a similar manner all portions of the cortex are brought into relation with the thalamus, axons from the cortical cells passing downward to terminate in tufts around the thalamic nuclei.

The tegmentum is intimately related to the thalamus, though the exact distribution of various strands of fibers is a subject of much discussion. Most of the fibers of the mesial fillet end in tufts around the cells of the ventral and lateral nuclei; other fibers pass directly to the cortex.

The optic tract sends fibers directly into the pulvinar, around the cells of which they terminate in brush-like expansions.

SUMMARY OF THE STRUCTURE OF THE MEDULLA, ISTHMUS, AND BASAL GANGLIA.

Structure of the Central Gray Matter.—Though the general arrangement of the central gray matter has been incidentally alluded to in the foregoing presentation of the anatomic features of the medulla and isthmus, it will be convenient to summarize its arrangement and structure at this point.

The gray matter of the cord, of the dorsal aspect of the medulla and pons, of the region surrounding the aqueduct of Sylvius, and of the lining of the third ventricle, constitute practically a continuous system, though presenting modifications in various parts of its extent. In the transition region of the spinal cord and medulla the gray matter of the former becomes much changed in shape owing to the shifting of position of the various tracts of white matter, until in the medulla and pons it is spread out in the form of a thin layer near their dorsal surfaces, where, together with the ependyma, it forms the floor of the fourth ventricle.

In the region of the aqueduct of Sylvius the gray matter again converges and ultimately surrounds the canal, to again expand at its anterior extremity, to form the lining of the third ventricle.

The Nerve-cells.—The nerve-cells in these different regions do not differ morphologically from those in the gray matter of the spinal cord. The corpus, or body of the cell, presents a number of dendrites as well as the sharply defined axon. As a rule, the cells are arranged in groups, or clusters, or nests, partially surrounded and enclosed by supporting tissue, and situated beneath the floor of the fourth ventricle and the floor of the aqueduct of Sylvius. From some of the cell groups axons pass ventrally through the white matter to merge on the ventral and lateral surfaces of the medulla, pons, and crura, where they are known as efferent or motor cranial nerves. From other groups of cells, axons cross the median line, and after joining the mesial fillet ascend toward the cerebrum. Around these latter cells the terminal filaments of the afferent or sensor cranial nerves arborize. The collection of cells found in the central gray matter may be divided into two groups—*efferent* and *afferent*.

The **efferent** cells, like those of the cord independent of a trophic influence, are motor in function, inasmuch as the excitation arising in them is transmitted outward through their related axons to muscles, glands, viscera or blood-vessels, imparting to them motion, either molar or molecular.

The **afferent** cells are largely sentient or receptive in function, inasmuch as the excitations brought to them by the afferent cranial nerves from skin and mucous membranes and from sense-organs, such as the tongue and ear, are received by them and transmitted through their ascending axons to the cortex of the cerebrum, where they are translated into conscious sensations.

Structure of the White Matter.—The white matter is composed of medullated nerve-fibers, and though arranged in a very complex manner may be divided into longitudinal and transverse fibers.

The *longitudinal fibers* which compose the main portion of the isthmus may be subdivided into (1) a ventral or pedal portion and (2) a dorsal or tegmental portion. The fibers constituting the *ventral* or *pedal* portion may for convenience be said to extend from the cerebral cortex to the pons, medulla, and spinal cord. They may be divided into three distinct tracts: *e. g.*, the pyramidal tract, the fronto-cerebellar tract, and the occipito-temporo-cerebellar tract (Fig. 243).

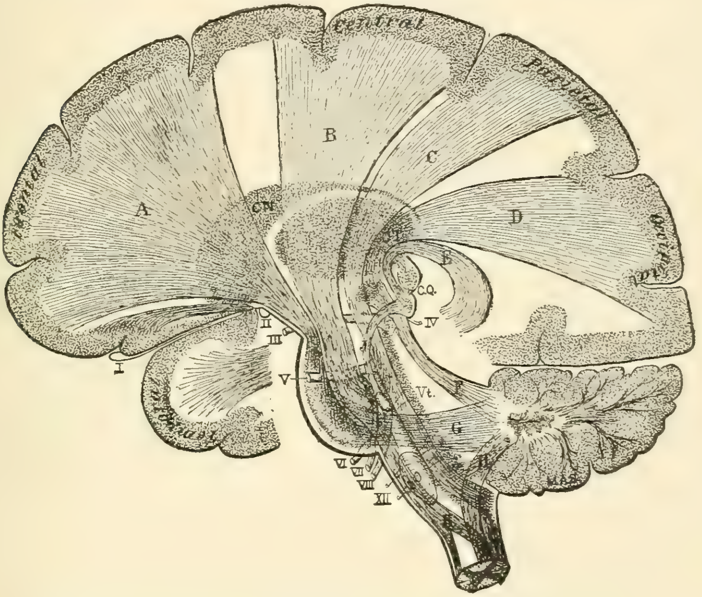

Fig. 243.—Diagrammatic Arrangement of the Projection Tracts Connecting the Cerebral Cortex with the Lower Nerve-centers. A. Fronto-cerebellar tract. B. The pyramidal or motor tract. C. Sensory tract. D. Visual tract from optic thalamus (O.T.) to the occipital lobe. E. Central auditory tract. F. Superior cerebellar peduncle. G. Middle cerebellar peduncle. H. Inferior cerebellar peduncle. C.N. Caudate nucleus. C.Q. Corpora quadrigemina. Vt. Fourth ventricle. The numerals refer to cranial nerves. J. Eighth nerve nucleus.—(*After Starr.*)

The *pyramidal tract* descends from the cortex of the cerebrum bordering the fissure of Rolando, passes through the posterior one-third of the anterior segment and the anterior two-thirds of the posterior segment of the internal capsule, the middle two-fifths of the crusta, behind the transverse fibers of the pons, to become the anterior pyramids of the medulla, beyond which it divides into the direct and crossed pyramidal tracts of the cord. In its course some of the fibers and their collaterals arborize around efferent cells from the anterior extremity of the aqueduct of Sylvius to the termination of the spinal cord.

The *fronto-cerebellar tract* descends from the cortex of the frontal portion of the anterior lobe, passes through the anterior portion of the anterior segment of the internal capsule, the inner fifth of the crusta to the pons, where its fibers terminate or arborize around the nucleus pontis of the same and opposite sides.

The *occipito-temporo-cerebellar tract* descends from the occipital and temporal lobes, passes to the inner side of the lenticular nucleus, and continues downward on the outer side of the crusta, occupying about one-fifth of its bulk, to the pons, where its fibers also arborize around the nucleus pontis of the same and opposite sides. By means of fibers in the middle peduncle these descending fibers are brought into relation with the cerebellum.

The fibers constituting the *dorsal* or *tegmental* portion of the longitudinal system may be said for convenience to extend from the posterior portion of the medulla and pons to the optic thalamus and cerebrum. They may be subdivided into several tracts: viz., the fillet, the posterior longitudinal bundle, Gowers' tract, etc.

The *fillet* or *lemniscus*, consisting of fibers having their origin partly from the cells of the cuneate and gracile nuclei and partly from the cells of the sensor end-nuclei of various sensor cranial nerves, occupies a region in the ventral and mesial portion of the tegmentum throughout its entire extent. Superiorly this mesial fillet divides into two portions, one of which passes to the thalamus and pregeminum (anterior corpus quadrigeminum), the other to the cortex of the parietal and limbic lobes. The fibers coming from the sensor end-nucleus of the auditory nerve (the lateral fillet) lie on the lateral aspect of the pons and crus. Superiorly they terminate in the postgeminum (the posterior corpus quadrigeminum).

The *posterior longitudinal bundle*, an upward extension of the fibers composing a portion of the ground bundle of the spinal cord, is located on either side of the median line just beneath the floor of the fourth ventricle and the aqueduct of Sylvius. As it passes upward collateral branches are given off, some of which arborize around the cell nuclei of the third, fourth, and sixth cranial nerves of the same side, while others cross the median line and arborize around the corresponding cell nuclei of the opposite side. Superiorly some of the fibers become related to cells in the thalamus and subthalamic region. This bundle of fibers appears to be mainly commissural in character.

Gowers' tract, the antero-lateral tract of the spinal cord, occupies a position in the lateral region of the formatio reticularis both in the medulla and pons. Continuing upward, it enters the mesial fillet, and in company with it passes through the posterior division of the internal capsule and finally terminates around cells in the cortex of the parietal lobe.

The *transverse fibers* of the isthmus are found in the pons. The fibers of the ventral as well as those of the more dorsal regions have their origin in nerve-cells in the cortex of the cerebellum. From their origin they pass through the cerebellar white matter, and through the middle peduncle as far as the median line, where they decussate with fibers coming from the opposite side. Beyond this point they pass to the cerebellar cortex. From their anatomic relations it is probable that these transverse fibers are commissural in character, bringing into relation opposite but corresponding regions of the cerebellar cortex. In addition to the commissural fibers other transverse fibers associate the cerebellar cortex with the gray matter in the pons on both the same and opposite sides. In this way the cerebellum is brought into relation with longitudinal fibers coming from and going to the cerebrum.

FUNCTIONS OF THE MEDULLA OBLONGATA, ISTHMUS, AND BASAL GANGLIA.

Microscopic examination of the white and gray matter of these various parts of the central nerve system shows that they are composed of nerve-cells and nerve-fibers which morphologically do not differ in essential respects from those found in the spinal cord, though their arrangement is far more complicated and involved. The functions of these closely related structures are in consequence equally complex and involved and but imperfectly known.

In a general way it may be said that by virtue of the presence of nerve-cells and definite tracts of nerve-fibers these structures collectively may be regarded as consisting:

1. Of centers for reflex actions; and—
2. Of conducting paths by which the various parts are brought into relation one with another and with the spinal cord, the cerebellum, and the cerebrum.

The Medulla Oblongata and Pons.—The gray matter situated in these structures—*i. e.*, just beneath the floor of the fourth ventricle—contains nerve-cells arranged in more or less well-defined groups which may be divided into *efferent* and *afferent*.

The *efferent cells* are the immediate sources of nerve impulses which are transmitted through efferent axons to various peripheral organs—muscles, glands, viscera and blood-vessels. Their activity may be excited by the same influences which excite the efferent cells of the spinal cord: *e. g.*, variations in the composition of the blood or lymph; the arrival of nerve impulses coming through afferent pathways in the spinal cord and through afferent cranial nerves; the arrival of nerve impulses coming through efferent pathways from the cerebrum. The peripheral activity resulting from their excitation may therefore be automatic or autochthonic, peripheral (reflex) or cerebral (volitional) in origin.

The *afferent cells* are sentient or receptive in function, inasmuch as they receive nerve energies coming through lower afferent pathways and transmit them through their related axons to the cortex of the cerebrum, where they are translated into conscious sensations.

The efferent cells give origin tq nerve-fibers which pass ventrally and become the efferent or motor cranial nerves.

The afferent cells give origin to fibers which pass to the cerebral cortex. Around both groups of cells, the afferent or sensor cranial nerves terminate in tuft-like expansions. In a subsequent section the origin, course, and distribution of the various cranial nerves will be considered. But as the function of the nerve is but to transmit energy from the cell of which it constitutes a part, the function ascribed to it may without impropriety be transferred to the cell itself.

Since it is by means of nerve-cells and their associated fibers that many important functions of organic life are initiated and maintained, it would naturally be expected from its extensive nerve connections that this region of the nerve system plays an extensive rôle in this respect. As the accomplishment of these functions requires the coöperation and coördination of a number of separate but related structures, it is evident that there must exist in the medulla and pons a number of coördinating mechanisms consisting of nerve-cells and nerve-fibers which are associated in various ways for the accomplishment of definite functions. To such a coördinating mechanism the term "center" has been given: *e. g.*, respiratory, cardiac, deglutitory, etc.*

The Medulla Oblongata and Pons as Centers for Reflex Activities.—Experimentation has shown that the medulla and pons contain a number of such centers, the more important of which are as follows:

1. *Cardiac centers,* which exert (1) an *accelerator* action over the heart's pulsations through nerve-fibers emerging from the spinal cord in the roots of the first and second dorsal nerves and reaching the heart through the sympathetic nerve; (2) an *inhibitor* or *retarding* action on the rate of the heart beat through efferent fibers in the trunk of the pneumogastric or vagus nerve. (See pages 312, 313.)
2. A *vaso-motor center,* which regulates the caliber of the blood-vessels throughout the body in accordance with the needs of the organs and tissues for blood, through nerve-fibers passing by way of the spinal nerves to the walls of the blood-vessels. (See page 376.)
3. A *respiratory center,* which coördinates the muscles concerned in the production of the respiratory movements. (See page 428.)

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* By the term center as here employed is meant a collection of nerve-cells and nerve-fibers occupying an area of greater or less extent, though its exact anatomic limits may not be accurately defined. That an area may merit the term center, it is necessary that its stimulation should increase, its destruction should abolish or impair, functional activity.

4. A *mastication center*, which excites to activity and coördinates the muscles of mastication. (See page 150.)
5. A *deglutition center*, which excites and coördinates the muscles concerned in the transference of the food from the mouth to the stomach. (See page 170.)
6. An *articulation center*, which coördinates the muscles necessary to the production of articulate speech.

In addition, the gray matter contains centers which influence the secretion of saliva, provoke vomiting, coördinate the muscles of the face concerned in expression, and control the secretion of the perspiration.

As Conducting Pathways.—The anterior pyramids of the medulla and their continuations through the more ventral portions of the pons, being portions of the general pyramidal tract, serve to conduct volitional efferent nerve impulses from higher portions of the brain to the spinal cord. Division of either of these pathways is at once followed by a loss of volitional control of the muscles below the section.

The dorsal or tegmental portion, containing the fillet and Gowers' tract, serves to transmit afferent nerve impulses from the spinal cord to higher portions of the brain. Transverse division of one-half of the dorsal portion of the pons is followed by complete anesthesia of the opposite half of the body without any impairment of motion.

The restiform bodies constitute a pathway between the spinal cord and the cerebellum. The transverse fibers of the pons associate opposite but corresponding portions of the cerebellar hemispheres.

The Crura Cerebri.—The crura cerebri consist *ventrally* of fibers which are largely derived from the pyramidal tracts and are continuous with the longitudinal fibers of the ventral portion of the pons and medulla; and dorsally of fibers continuous with those coming through the lower portions of the tegmentum. Hence they are conductors of motor impulses in the former and of sensor impulses in the latter region. It is not definitely known as to whether reflex actions take place through the gray matter, the locus niger, or not.

The gray matter beneath the aqueduct of Sylvius contains nerve-cell groups which are centers for reflex actions in connection with ocular movements: *e. g.*, closure of the lids, contraction of the sphincter pupillæ, convergence of the eyes, etc.

The Corpora Quadrigemina.—From the anatomic relation of the anterior quadrigeminal body (the pregeminum) to the optic tract, on the one hand, and to the optic radiation, on the other, the inference can be drawn that it is in some way essential to the performance of the visual process. Experimental investigations and pathologic changes support the inference.

Irritation of the pregeminum in monkeys on one side is followed by dilatation of the pupils first on the opposite side and then almost immediately on the same side. The eyes at the same time are also widely opened and the eyeballs turned upward and to the opposite side. If the irritation be continued, motor reactions are exhibited in various parts of the body. Destruction of the pregeminum in both monkeys and rabbits is followed by blindness, dilatation and immobility of the pupils, with marked disturbance of equilibrium and locomotion (Ferrier).

From the anatomic relation of the posterior quadrigeminal body (the postgeminum) to the lateral fillet, the basal tract for hearing, the inference may be drawn that it is in some way connected with the auditory process.

Stimulation of the postgeminum gives rise to cries and various forms of vocalization. Pathologic states of this body are also attended by impairment of hearing and disorders of the equilibrium.

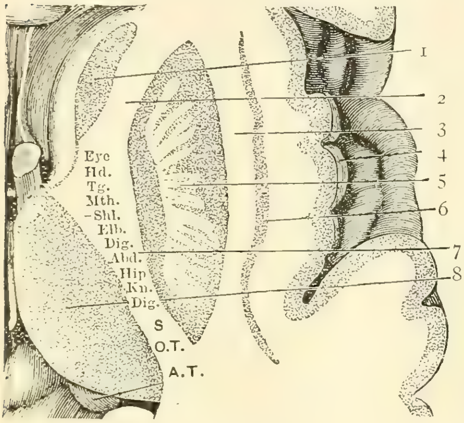

Fig. 244.—Horizontal Section of the Internal Capsule Showing the Position and Relation of the Motor Tracts for the Eye, Head (Hd.), Tongue (Tg.), Mouth (Mth.), Shoulder (Shl.), Elbow (Elb.), Digits of Hand (Dig.), Abdomen (Abd.), Hip, Knee (Kn.), Digits of Foot (Dig.). S. Sensor tract. O. T. Optic tract. A. T. Auditory tract. 1. Caudate nucleus. 2. Anterior segment of internal capsule. 3. External capsule. 4. Island of Reil. 5. Lenticular nucleus. 6. Claustrum. 7. Posterior segment of internal capsule.—(*Modified from Landois.*)

From the foregoing facts it is probable that the corpora quadrigemina are associated with station and locomotion. Ferrier assumes that in these bodies "sensory impressions, retinal and others, are coördinated with adaptive motor reactions such as are involved in equilibration and locomotion."

The Corpora Striata.—The relation of these bodies to the pyramidal motor tract would indicate that they are in some way connected with motor activities. Their function, however, is obscure. While stimulation of one corpus produces convulsion of the muscles of the opposite side of the body, and destruction gives rise to paralysis of the corresponding muscles, it is difficult, owing to the intimate association of the white and the gray matter, to state to which the phenomena are to be attributed. The evidence at hand points to the conclusion that if a lesion is limited to the gray matter the paralysis which might result would be but temporary and of short duration. The pathologic evidence is of a similar character. Gowers is of the opinion, that if the lesion is small and at a sufficient distance from the white fibers of the capsule, there may even be no initial hemiplegia; neither motor nor sensory paralysis will arise if the lesion is confined to the gray matter.

It is stated by some experimenters that localized injuries, both experimental and pathologic, are followed by a persistent rise of temperature, varying from 1° to 2.6° C.

The Optic Thalami.—From the anatomic relation of the optic thalami to the general and special sense nerve-tracts, on the one hand, and to the cerebral cortex, on the other hand, it is assumed that they are connected with the production of sensations both general and special, and act as intermediates between the peripheral sense-organs and the cortex.

The results of experimental stimulation and destruction of the thalami are extremely contradictory and fail to throw much light on their functions. Ferrier states that destruction of the posterior part of one thalamus produced blindness in the opposite eye and impairment of the sense of touch and pain in the opposite side of the body. In a patient under the care of Hughlings-Jackson there was blindness in the right half of each eye, loss of hearing in the left ear, impairment of taste on the left side of the tongue, and a diminution of the sense of touch on the left side of the body. Postmortem examination showed a patch of softening in the posterior part of the right thalamus, the remainder of the organ being normal.

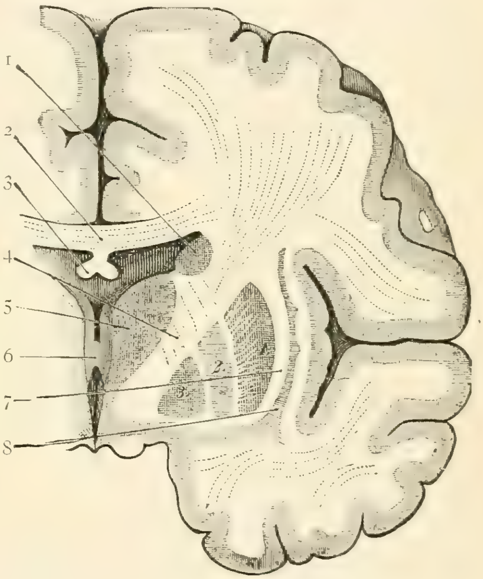

Fig. 245.—Vertical Section Through the Right Cerebral Hemisphere in Front of the Gray Commissure. 1. Caudate nucleus. 2. Corpus callosum. 3. Pillars of the fornix. 4. *Internal capsule.* 5. Optic thalamus. 6. Gray commissure. 7. External capsule. 8. Claustrum (1, 2, 3, the three divisions of the lenticular nucleus).—(*Landois.*)

It is probable that in the thalamus visual, tactile, and labyrinthine impressions are received, coördinated, and reflected outward, with the result of producing various adaptive motor reactions connected with station and equilibrium. It is also believed by some investigators to act as an intermediate between emotional states and their expression in the muscles of the face, this power being lost in certain pathologic conditions. The power of regulating the temperature of the body has also been assigned to the thalamus, as destruction of its anterior extremity is usually followed by a rise in temperature.

The Internal Capsule.—The internal capsule has been shown by the results both of experiment and of pathologic processes to be, first, a pathway for the transmission of nerve impulses from the cerebral cortex to the pons, medulla, and spinal cord, which give rise to contraction of the muscles of the opposite side of the body; and, second, a pathway for the transmission of nerve impulses coming from skin, mucous membrane, muscles, and special sense-organs to the cortex, where they give rise to sensations general and special. It is therefore the common motor and sensor pathway. For the reason that it transmits both motor and sensor impulses, and for the further reason that it is frequently the seat of pathologic lesions which are followed by either a loss of motion or sensation or both, the internal capsule is one of the most important parts of the central nerve system. As shown in Fig. 244, it consists of two segments or limbs united at an obtuse angle, the knee or elbow, which is directed toward the median line. The *motor* tract is confined to the posterior one-third of the anterior segment and the anterior two-thirds of the posterior segment. The *sensor* tract is confined to the posterior one-third of the posterior segment, the extreme end of which also contains the optic and auditory tracts.

The region of the anterior segment in front of the motor tract contains the fibers of the fronto-cerebellar tract, the function of which is unknown.

The motor region contains fibers which descend from the cerebral cortex to nerve-centers situated in the gray matter beneath the aqueduct of Sylvius, in the gray matter beneath the floor of the fourth ventricle, and in the anterior horns of the gray matter of the spinal cord, and which in turn are connected by the cranial and spinal nerves with the muscles of the eye, head, face, trunk, and limbs. The positions occupied by these different tracts are shown in Fig. 244.

The relation of the internal capsule to the caudate nucleus and the optic thalamus internally, and to the lenticular nucleus externally, is also shown in a vertical section of the cerebrum made in front of the gray commissure (Fig. 245). From the fact that the internal capsule contains efferent or motor tracts, and afferent or sensor tracts, it is evident that a destructive lesion of the motor tract would be followed by a loss of motion; and of the sensor tract, by a loss of sensation on the opposite side of the body.

CHAPTER XXI.

THE CEREBRUM.

The **cerebrum** is the largest portion of the encephalon, constituting about 85 per cent. of its total weight. In shape it is ovate, convex on its outer surface, narrow in front and broad behind. It is divided by a deep longitudinal cleft or fissure into halves, known as the cerebral hemispheres. The hemispheres are completely separated anteriorly and posteriorly by this fissure, but in their middle portions are united by a broad white band, the corpus callosum. Each hemisphere or hemi-cerebrum is convex on its outer aspect, and corresponds in a general way with the cavity of the skull; the inner or mesal surface is flat and forms the lateral boundary of the longitudinal fissure.

The surface of each hemi-cerebrum presents a series of alternate indentations and elevations, known respectively as fissures or sulci, and convolutions or gyres. A knowledge of the situation and extent of the principal fissures and convolutions, as well as of their relation one to another, is essential to a clear understanding of many physiologic processes, clinical phenomena, and surgical procedures, The general arrangement of the primary fissures and convolutions is represented in Figs. 246 and 247.

Fissures.—

1. The *fissure of Sylvius*, one of the most important of the primary fissures, is found on the side of the cerebrum. It begins at the base and extends upward, outward, and backward to a point corresponding to the eminence of the parietal bone, where it usually terminates in a more or less vertically directed branch, the epi-sylvian branch. Anteriorly a short branch is given off which passes upward and forward into the frontal lobe and known as the pre-sylvian; a horizontal branch is known as the sub-sylvian. The Sylvian fissure is the first to appear in the development of the fetal brain, becoming visible at the third month. In the adult it is deep and well marked and divides the hemi-cerebrum into a frontal and a temporo-sphenoidal lobe.
2. The *fissure of Rolando*, or central fissure, equally important, is found on the superior and lateral aspects of the cerebrum. It runs from a point on the convexity of the hemisphere near the median line transversely outward and downward toward the fissure of Sylvius, but as a rule does not pass into it. It divides the frontal from the parietal lobe. The inclination of the central fissure is such as to form with the longitudinal fissure an angle of about 67 degrees.

3. The *intra-parietal fissure* arises a short distance behind the central fissure. It then runs upward, backward, and downward to terminate near the posterior extremity of the parietal lobe. It divides the parietal lobe into a superior and an inferior portion.
4. The *parieto-occipital fissure,* situated on the mesal surface of the hemisphere, divides the latter into a parietal and an occipital lobe. It begins as a deep notch on the surface of the hemisphere, and is then continued downward and forward until it enters the calcarine fissure. (Fig. 247.)

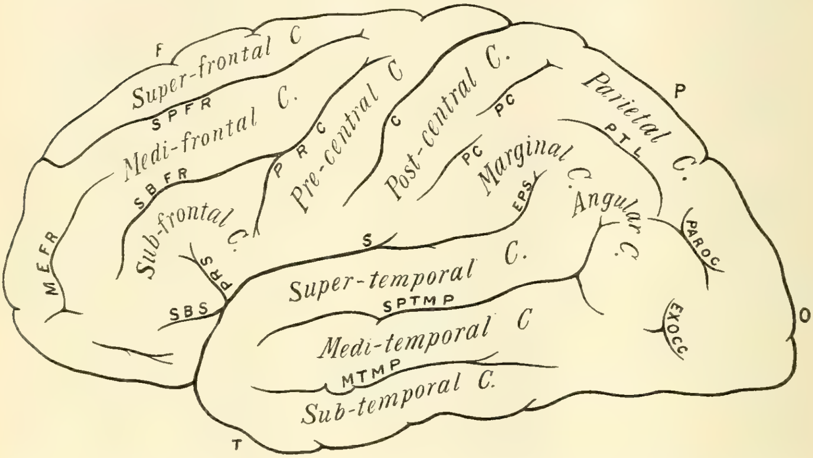
F
Super-frontal C
SPFR
Medi-frontal C.
Pre-central C
PRC
C
Post-central C.
PC
PC
Marginal C.
Parietal C.
P
PTL
SBFR
Sub-frontal C.
MEFR
EPS
Angular C.
PAROC
S
PRS
SBS
Super-temporal C.
SPTMP
Medi-temporal C
MTMP
Sub-temporal C.
EXOCC
O
T

FIG. 246.—DIAGRAM SHOWING FISSURES AND CONVOLUTIONS ON THE LATERAL ASPECT OF THE LEFT HEMI-CEREBRUM. F. Frontal. P. Parietal. T. Temporal and O. Occipital lobes. S. Fissure of Sylvius. E P S. Epi-sylvian, P R S. Pre-sylvian, S B S. Sub-sylvian fissures. C. Central fissure or Fissure of Rolando. P R C. Pre-central fissure. S P F R. Super-frontal fissure. M E F R. Medi-frontal fissure. S B F R. Sub-frontal fissure. P C. P C. Post-central fissure. P T L. Parietal fissure. P A R O C. Par-occipital, EXOCC. Ex-occipital fissures. SPTMP. Super-temporal fissure. MTMP Medi-temporal fissure.

5. The *calcarine fissure* begins on the posterior extremity of the mesal surface of the occipital lobe. From this point it passes downward and forward to unite with the parieto-occipital fissure.
6. The *para-central fissure* begins at the supero-mesal border of the hemisphere. It then passes downward and forward for a variable distance and then turns upward enveloping a lobule known as the *para-central* lobule.
7. The *super-callosal fissure* extends from a point just anterior to the para-central lobule downward and forward below the rostrum of the corpus callosum.

Secondary fissures of more or less importance are present in the different lobes, subdividing the surface into convolutions: *e. g.*, in the frontal lobe are found the *pre-central*, the *super-frontal*, *medi-frontal and sub-frontal fissures;* in the temporal lobe the *super-temporal* and *medi-temporal fissures.*

Convolutions.—The convolutions or gyres are the portions of the cerebral surface comprised between the fissures. The arrangement of the surface is such that only the more superficial portions are visible. The depth of the convolution, the portion bordering the fissure, is concealed from view. Each lobe presents a series of such convolutions which differ considerably in their relative physiologic importance.

The Frontal Lobe.—The frontal lobe presents on its convex surface four convolutions: viz., the anterior or pre-central convolution, and the super-, medi, and sub-frontal convolutions.

1. The *anterior or pre-central convolution* is situated just in front of the Rolandic or central fissure, with which it corresponds in direction. It is continuous above with the super-frontal and below with the sub-frontal convolution.

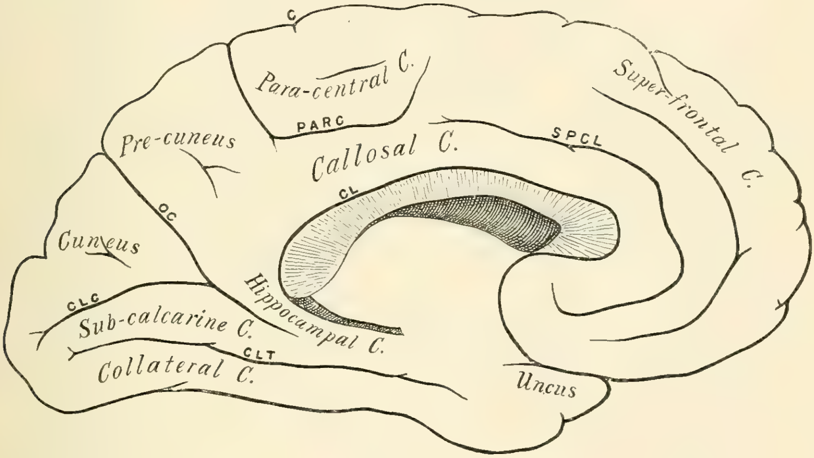

Fig. 247.—Diagram Showing Fissures and Convolutions on the Mesal Aspect of the Left Hemi-cerebrum. C. Upper extremity of the central fissure. P A R C. Para-central fissure. S P C L. Super-callosal fissure. C L. Callosal fissure. O C. Occipital fissure. C L C. Calcarine fissure. C L T. Collateral fissure.

2. The *super-frontal convolution* is bounded internally by the longitudinal fissure and externally by the super-frontal fissure. From the upper end of the pre-central convolution, with which it is continuous, it runs forward and downward to the anterior extremity of the frontal lobe, where it turns backward and rests on the orbital plate of the frontal bone.
3. The *medi-frontal convolution* is situated on the side of the lobe, between the super-frontal fissure above and the medi-frontal fissure below. Its general direction is downward and forward.
4. The *sub-frontal convolution* winds around the pre-sylvian branch of the fissure of Sylvius in the anterior and inferior portion of

the frontal lobe. It is continuous posteriorly with the lower end of the pre-central convolution.

The Parietal Lobe.—The parietal lobe presents three well-marked convolutions: viz., the posterior or post-central convolution, and the super- and sub-parietal. The latter is again subdivided into the marginal and the angular convolution.

1. The *posterior or post-central convolution* is situated just behind the Rolandic or central fissure, with which it corresponds in direction. Above, it is continuous with the super parietal convolution; below, with the marginal and the pre-central convolutions.
2. The *super-parietal convolution* is bounded internally by the longitudinal fissure and externally by the intra-parietal fissure. From the upper end of the post-central convolution, with which it is connected, it runs downward and backward as far as the parieto-occipital fissure.
3. The *sub-parietal convolution* is connected anteriorly with the post-central convolution. Passing backward, it winds around the superior extremity of the fissure of Sylvius, in which situation it is known as the *supra-marginal* convolution. Beyond this point it divides into two portions, one of which runs forward into the temporal lobe above the super-temporal fissure, while the other runs downward and backward, following the intra-parietal fissure to its termination. At this point it makes a sharp bend and runs forward into the temporal lobe just beneath the super-temporal fissure. In the neighborhood of the bend it is generally known as the *angular convolution* or *gyrus*.

The Temporo-sphenoidal Lobe.—The temporo-sphenoidal lobe presents on its external surface three well-marked convolutions: viz., the *super-*, the *medi-*, and the *sub-temporal*, separated by the super- and medi- temporal fissures. These three convolutions are in a general way parallel with each other, and pursue a direction from before backward and upward. Anteriorly, they are fused together, but posteriorly their connections are somewhat different. The super-temporal is continuous behind and above with the *supra-marginal* convolution, and behind and below with the *angular* convolution or gyre. The medi-temporal blends with the preceding and with the middle occipital. The sub-temporal is continuous with the inferior occipital.

The Occipital Lobe.—The occipital lobe is triangular in shape and forms the posterior apex of the hemisphere. Its base on the external surface is formed by an imaginary line drawn from the parieto-occipital fissure to the pre-occipital notch on the inferior and lateral border. The external surface presents three convolutions—the superior, middle, and inferior occipital.

The **inner or mesal surface** of the hemisphere, formed in part by the frontal, the parietal, the occipital, and the temporal lobes, presents several convolutions of much physiologic interest, viz.:

1. The *callosal convolution*, situated between the super-callosal fissure and the corpus callosum. From its origin anteriorly at the base of the brain this convolution passes backward, gradually increasing in width as it approaches the posterior extremity of the corpus callosum. At this point it again narrows and descends between the calcarine and hippocampal fissures to blend with the hippocampal convolution.
2. The *gyrus hippocampus*, formed by the union of the posterior extremity of the callosal convolution and the sub-calcarine convolution is situated just below the dentate or hippocampal fissure. Anteriorly it becomes enlarged, and just behind the apex of the temporal lobe turns backward and inward to form a hook-shaped eminence, the *uncinate gyrus* or *uncus*.

   The *limbic lobe* is the name given to an area of the brain which includes, among other structures, the callosal convolution, the gyrus hippocampus, and the uncus. As forming a part of this general lobe may be mentioned the dentate fascia, the striæ and peduncle of the corpus callosum, the septum lucidum, the fornix, and the infracallosal gyrus.
3. The *collateral convolution* is bounded by the collateral fissure above, and its inferior border extends from the occipital lobe to the anterior pole of the temporal lobe.
4. The *quadrate lobule, or precuneus*, a square-shaped convolution, is situated between the posterior termination of the para-central fissure and the parieto-occipital fissure. It blends with the callosal convolution, on the one hand, and with the parietal lobule on the other.
5. The *cuneus*, a triangular or wedge-shaped convolution or lobule, is situated on the mesal surface of the occipital lobe between the parieto-occipital and calcarine fissures.

The Insula or Island of Reil.—This anatomic structure consists of a triangular shaped cluster of six small convolutions situated at the bifurcation of the Sylvian fissure and concealed from view by the convolutions bordering it, spoken of collectively as the operculum. These convolutions are connected with the frontal, the parietal, and the temporal lobes.

Structure of the Gray Matter of the Cortex.—The gray matter, the cortex of the cerebrum, varies from two to four millimeters in thickness. When examined with a lens of low power, it presents a laminated appearance, due to differences in color and arrangement of its constituent elements. With higher magnification the cortex is seen to consist of neuroglia cells, nerve-cells with specialized dendrites and axons, medullated and non-medullated nerve-fibers, blood-vessels, connective tissue, etc.—all of which are arranged and interblended in a most intricate manner. Notwithstanding the complexity of its structure, modern histologic methods have enabled Cajal to divide it into four fairly distinct layers or zones, from without inward, as follows (Fig. 248):

1. *The Molecular Layer.*—The most superficial portion of this layer consists mainly of neuroglia or glia cells, the processes of which interlace in all directions, forming a distinct sheath just beneath the pia. The deeper portions of this layer contain a specialized type of nerve-cell (Cajal cells), of which there are several varieties. These cells give off nerve-fibers which pursue a horizontal direction for a variable distance, but in their course give off collateral branches which ascend to the outer surface of the layer. Among these structures are to be found, also, dendritic processes of cells situated in the subjacent layer. The terminal filaments of medullated nerve-fibers coming from nerve-cells in lower regions of the encephalo-spinal axis are also present, but for the most part they pursue a tangential direction.

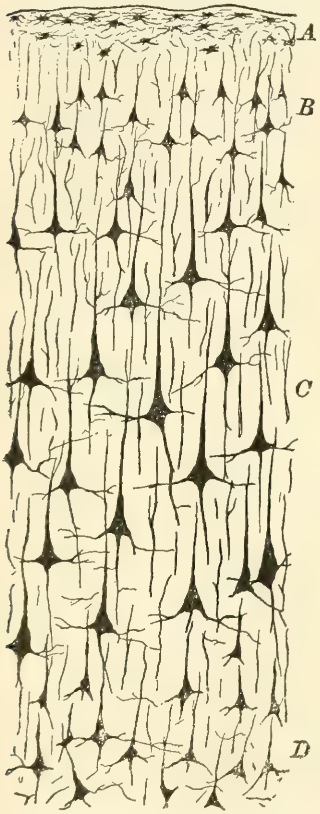

Fig. 248.—Section of the Cerebral Cortex (Motor Area) of Child, Stained by Golgi's Silver Method. *A.* Layer of neuroglia cells. *B.* Layer of small pyramidal ganglion cells. *C.* Layer of large pyramidal cells. *D.* Layer of irregular smaller cells.—(*Piersol.*)

2. *The Layer of Small Pyramidal Cells.*—This layer consists mainly of nerve-cells, the majority of which are pyramidal in shape and of small size. Other cells, however, are present, which present a variety of shapes, for which reason the layer was at one time termed the ambiguous layer. The apical process of the pyramidal cells is broad at the base, but narrows rapidly as it passes upward. It frequently divides into several branches, each of which develops club-shaped processes or gemmules, which give to it a feathery appearance. Dendrites are also given off from the sides and base of the cell-body. From the base a single axon descends which ultimately becomes the axis-cylinder of a medullated nerve.
3. *The Layer of Large Pyramidal Cells.*—The nerve-cells of this layer, as the name implies, are also pyramidal in shape, but of large size. Each cell presents the same features as the cells of the

preceding layer, with the exception that the apical process is larger, better developed, and branches more freely. All the dendrites are extensively provided with gemmules. The axon is well developed, sharply defined, and smooth. After giving off collateral branches, the axon descends into the cerebrum and becomes a medullated nerve-fiber.

4. *The Layer of Polymorphous Cells.*—In this layer the nerve-cells present a variety of forms: *e. g.*, spindle, polygonal, pyramidal, etc. The spindle form is the most common. From either end of the spindle a large dendrite emerges which soon branches and becomes gemmulated. The axon is well defined and it soon descends into the white matter.

The Number of Cortical Cells.—Attempts have been made by various histologists to estimate the total number of functional nerve-cells in the cerebral cortex of man. Though the estimates are widely different, the lowest presents numbers which are beyond comprehension. Thus, Meynert's estimate is 612 millions; Donaldson's 1200 millions; while Thompson's is 9200 millions.

Structure of the White Matter.—The white matter of the cerebrum consists of medullated nerve-fibers which, though intricately arranged, may be divided into three systems: viz., the commissural, the association, and the projection.

1. *The commissural system.* The fibers which compose this system unite corresponding areas of the cortex of each hemisphere. The fibers from the frontal, parietal, and occipital lobes cross in the median line and form a band of transversely arranged fibers, the corpus callosum. The fibers which unite the corresponding areas of the temporo-sphenoidal lobes cross in the anterior commissure. All the commissural fibers are the axons of nerve-cells, in the cortex, the terminals of which are to be found in the cortex of the opposite side.
2. *The association system.* The fibers which compose this system unite neighboring as well as distant parts of the same hemisphere, and may therefore be divided into long and short fibers. They associate the inexcitable or association areas with the excitable or projection areas.
3. *The projection system.* The fibers composing this system unite certain areas of the cortex of the cerebrum with the basal ganglia, the pons, medulla oblongata, and spinal cord. They may be divided into: (1) afferent fibers which have their origin in the lower nerve-centers at different levels and thence pass to the cortex; and (2) efferent fibers which have their origin in the cortex and thence pass to the lower nerve-centers, terminating at different levels. The former are also termed the *cortico-afferent* or *cortico-petal;* the latter, *cortico-efferent* or *cortico-fugal.*

The *afferent fibers*, the so-called sensor tract, which transmit nerve impulses coming from the general periphery and the sense-organs, pass through the tegmentum as the mesial and lateral fillets, and thence to the cortex directly by way of the internal capsule, or indirectly through the intermediation of the thalamic and subthalamic nuclei. The distribution of these fibers to the various areas of the cortex will be found in following paragraphs.

The *efferent fibers* of the so-called motor tract which transmit motor or volitional nerve impulses from the cortex to the pons, medulla, and spinal cord, emerge from the layer of pyramidal cells of the gray matter of the anterior or the pre-central convolution, the paracentral lobule and immediately adjacent areas. From this origin the axons descend through the white matter of the corona radiata, converging toward the internal capsule, into and through which they pass, occupying the anterior two-thirds of the posterior limb or segment. Beyond the capsule they continue to descend, occupying the middle three-fifths of the pes or crusta of the crus cerebri, the ventral portion of the pons, and eventually the anterior pyramid of the medulla oblongata. At this point the tract divides into two portions, viz.:

1. A large portion, containing from ninety-one to ninety-seven per cent. of the fibers, which decussates at the lower border of the medulla and passes down the lateral column of the cord, constituting the *crossed pyramidal tract.*
2. A small portion, containing from three to nine per cent. of the fibers, which does not decussate at the medulla, but passes down the inner side of the anterior column of the same side, constituting the *direct pyramidal tract* or column of Türck.

After passing through the internal capsule, and as it descends through the crus, pons, and medulla, the cortico-efferent tract gives off a number of fibers which cross the median line and arborize around the nerve-cells in the gray matter beneath the aqueduct of Sylvius (the nuclei of origin of the third and fourth cranial nerves), and around the nerve-cells in the gray matter beneath the floor of the fourth ventricle (the nuclei of origin of the remainder of the motor cranial nerves). The remaining fibers go to form the crossed and direct pyramidal tracts and arborize around the cells in the anterior horn of the gray matter of the opposite side of the cord at successive levels. By this means the cortex is brought into anatomic and physiologic relation with the general musculature of the body through the various cranial and spinal motor nerves. (See Fig. 236, page 517.)

The *fronto-cerebellar* and the *occipito-temporo-cerebellar* tracts are also efferent tracts and parts of the projection system. The fronto-cerebellar, originating in the nerve-cells of the cortex of the frontal lobe, passes down to and through the internal capsule, occupying the anterior one-third of the anterior segment. It then descends along the inner side of the crus cerebri to the pons, where its fibers arborize around the cells of the *nucleus pontis.* Through the intermediation of these cells this tract is brought into relation with the cerebellum of the same but chiefly of the opposite side. The occipito-temporal tract, originating in the cells of the cortex of both the occipital and temporal lobes, passes downward and inward toward the lenticular nucleus, beneath which it passes to enter the outer one-fifth of the crusta. It then enters the pons, and through the nucleus pontis also comes into relation with the cerebellum of both sides. (See Fig. 243, page 529.)

THE FUNCTIONS OF THE CEREBRUM.

The functions of the cerebrum comprehend, in man at least, all that pertains to sensation, cognition, feeling, and volition. All subjective experiences, which in their totality constitute mind, are dependent on and associated with the anatomic integrity and the physiologic activity of the cerebrum and its related sense-organs, the eye, ear, nose, tongue, etc.

From an examination of the anatomic development of the brain in different classes of animals, in different men and races of men, and from a study of the pathologic lesions and the results of experimental lesions of the brain, evidence has been obtained which reveals in a striking manner the intimate connection of the cerebrum and all phases of mental activity.

1. *Comparative anatomic* investigations show that there is a general connection between the size of the brain, its texture, the depth and number of convolutions, and the exhibition of mental power. Throughout the entire animal series an increase in intelligence goes hand in hand with an increase in the development of the brain. In man there is an enormous increase in size over that of the highest animals, the anthropoid apes. The most cultivated races of men have the greatest cranial capacity, that of the educated European or American being approximately 92.1 cubic inches (1835 c.c.); while that of the Australian is but 81.7 cubic inches (1628 c.c.). Men distinguished for great mental power usually have large and well-developed brains; *e. g.*, that of Cuvier weighed 64.4 ounces (1830 grams); that of Abercrombie, 63 ounces (1786 grams). A large intelligence, however, is not incompatible with a much smaller brain weight; thus, the brain of Helmholtz weighed but 50.8 ounces (1440 grams); that of Leidy, 49.9 ounces (1415 grams); that of Liebig, 47.7 ounces (1352 grams). The average arithmetic brain weight of 96 distinguished men was found to be 51.9 ounces (1473 grams) (Spitzka).
2. *Pathologic lesions* and mechanic injuries which disorganize the cerebrum are at once followed by a disturbance or an entire suspension of mental activity. Concussion of the brain or sudden compression from a hemorrhage destroys consciousness. Physical and chemic alterations of the gray matter of the cerebrum have been shown to coexist with insanity, loss of memory, of articulate speech, etc. Congenital defects of organization are accompanied by a deficiency in mental capacity and the higher

instincts. Under such circumstances no great advance in brain development is possible and the intelligence remains at a low level. In congenital idiocy the brain is small, imperfectly developed, and wanting in proper chemic composition.

3. *Experimental lesions* of the brain in lower animals are attended by results similar to those observed in disease or after injury in man. Removal of the cerebrum in the pigeon completely abolishes intelligence and destroys the capability of performing volitional movements. The pigeon remains in a state of profound stupor, though retaining the capability of executing reflex or instinctive movements. It can temporarily be aroused by loud noises, light placed before the eyes, pinching of the toes, etc., but it soon relapses into a condition of quietude. Coincident with the destruction of the cerebrum there occurs a loss of memory, reason, and judgment, and the animal fails to associate the impressions with any previous train of ideas. The higher the animal in the scale of development, the more striking is the loss of mentality after removal of the cerebrum.

4. *Experimental interference* with the blood-supply to the cerebrum is followed by a diminished or complete cessation of its activities. There is perhaps no organ of the body that is so directly dependent upon its blood-supply for the continuance of its activities as the cerebrum. The supply of blood is furnished by four large blood-vessels: viz., the two carotid and the two vertebral arteries. These vessels, after entering the cavity of the skull, give off branches which unite to form the "circle of Willis." From this circle, large branches are given off which enter the cerebrum and distribute blood to all its parts. After passing through the capillaries the blood, greatly altered in chemic composition, is returned by large veins. The large volume of blood that is present in the brain and the marked changes in composition that it undergoes while passing through the brain indicate a very active and complex metabolism in this organ. By means of the anatomic arrangement of the blood-vessels at the base of the brain, the blood-supply is equalized. It also explains why, when one, or even two, of the four large vessels are occluded by pathologic deposits or surgical procedures, brain activity continues, though perhaps diminished in degree. Occlusion of all four vessels, however, is at once followed by a complete abolition of all forms of cerebral activity. An experiment performed by Brown-Séquard illustrates the dependence of cerebral activity on the blood-supply. A dog was beheaded at the junction of the neck and chest. After a period of ten minutes all evidences of life had entirely ceased. Four tubes connected with a reservoir of warm defibrinated blood were then connected with the four arteries of the head. By means of a pumping apparatus imitating the action of the heart the blood was driven into and

through the brain. After a few minutes cerebral activity returned, as shown by contraction of the muscles of the face and eyes. The character of the contractions were such as to convey the idea that they were directed by the will. These vital manifestations continued for a period of fifteen minutes, when on the cessation of the artificial circulation they disappeared, and the head exhibited once again the usual phenomena observed in dying: viz., contraction and then dilatation of the pupils and convulsive movements of the muscles of the face.

Localization of Functions in the Cerebrum.—By the term localization of functions is meant the assignment of definite physiologic functions to definite anatomic areas of the cerebral cortex. From experiments made on the brains of animals, by the observation and association of clinical symptoms with pathologic lesions of the central nerve system, and from observation of the developmental stages of the embryonic brain, it has been established in recent years:

1. That the general and special sense-organs of the body are associated through afferent nerve-tracts with definite though perhaps not sharply delimited areas of the cerebral cortex; and—
2. That certain areas of the cortex are associated through efferent nerve-tracts with special groups of skeletal or voluntary muscles.

Experimental excitation of a cortical area associated with a sense-organ is undoubtedly attended by the production of a sensation at least similar to that produced by peripheral excitation of the sense-organ itself; *destruction* of the area is followed by an abolition of all the sensations associated with the sense-organ. For these reasons such areas are termed *sensor.*

Excitation of a cortical area associated with a group of skeletal muscles is attended by their contraction; *destruction* of the area is followed by their relaxation or paralysis. For these reasons such areas are termed *motor.*

Since the sense-organs are remote from the brain and the impressions made upon them by the objective world can be utilized by the mind, only after they have been reproduced in the cortical areas, it may be said that each sense-organ has its special area in the cortex by which it is represented, or, in other words, each sense-organ has a cortical area of representation.

Since the muscles are remote from the brain and since they contract in response to the discharge of nerve impulses from the cells of the cortical motor areas, it may be said that the activities of the motor areas are represented by the contractions of the muscles; in other words, that the cortical motor areas have areas of representation in the general skeletal musculature. It is usually stated, however, in the reverse way: viz., that the muscle movements have areas of representation in the cortex.

The cortex of the cerebrum may therefore be compared to a mosaic made up, partially at least, of sensor and motor areas which respectively represent sense-organs and motor organs, and which hear a definite anatomic and physiologic relation one to the other. Their coöperation is essential to the normal performance of all forms of cerebral activity.

A knowledge of the situation of these areas, the order of their development, the effects that arise from their stimulation or follow their destruction, are matters of the highest importance in the study of cerebral activity and indispensable to the physician in the localization of lesions which manifest themselves in perversions or abolition of sensations and in convulsive seizures or paralyses.

The Sensor Areas.—The sensor areas which should theoretically be present in the cortex are primarily those which receive and translate into conscious sensations nerve impulses, developed by changes going on in the body itself; and secondarily those which receive and translate into conscious sensations the nerve impulses developed in the special sense-organs by the impact of the external or objective world. In the former areas, are received the nerve impulses that come from the skin, mucous membranes, muscles, viscera, etc., and give rise to cutaneous, muscle, and visceral sensations. In the latter areas are received the nerve impulses that come from the sense-organs and give rise to tactile, gustatory, olfactory, auditory, and visual sensations. A number of such sense areas may be predicated: *e. g.*, areas of *cutaneous* and *muscle sensibility*, of *gustatory*, *olfactory*, *auditory*, and *visual sensibility*.

The Motor Areas.—The motor areas which should theoretically be present in the cortex are those which in consequence of the discharge of nerve impulses excite contraction of special groups of muscles and which, from their coördinate and purposive character, are conventionally termed volitional. Five such general motor areas may be predicated: *e. g.*, one for the muscles of the head and eyes, one for the muscles of the face and associated organs, and others for the muscles of the arm, leg, and trunk. They are usually designated as *head and eye*, *face*, *arm*, *leg*, and *trunk motor areas*.

The existence and anatomic location of these areas in the cortex of animals have been determined by the employment of two methods of experimentation: viz., stimulation and destruction or extirpation; the first by means of the rapidly repeated induced electric currents, the second by the electric cautery and the knife. If the stimulation or excitation of any given area is followed by contraction and its destruction by paralysis of muscles, it is assumed that the area is *motor* in function—is a *center of motion.* If the stimulation of a given area is attended by phenomena which indicate that the animal is experiencing sensation, and its destruction by a loss of this capability or the loss of a special sense, it is assumed that the area is *sensor* in function—is an area of *special sense.* The animals generally employed for experiments of this character are dogs and monkeys, though other animals have frequently been employed by different investigators. Of all animals, the monkey is the most frequently selected, as the configuration of the brain in its general outlines more closely resembles that of man than does the brain of any other animal. The results therefore which are obtained, there is every reason to believe, are the results, in their general outlines, that would follow stimulation of the human brain if this were possible under the same conditions. Indeed, the clinic symptoms which arise during the development of pathologic processes, and the phenomena which occur during surgic procedures for the removal of growths and pathologic cortical areas, justify the conclusion that the chart of the motor and sensor areas of the monkey brain may be transferred to the human brain without introducing any serious errors.

The Sensor Areas of the Monkey Brain.—From experiments made on the brains of monkeys, Ferrier, Schäfer, Horsley, and many others have mapped out, though not with a high degree of definiteness and certainty, the sensor areas, stimulation of which gives rise to sensation, destruction to loss of sensation. A diagrammatic represensation of these areas is shown in Fig. 249 and Fig. 250.

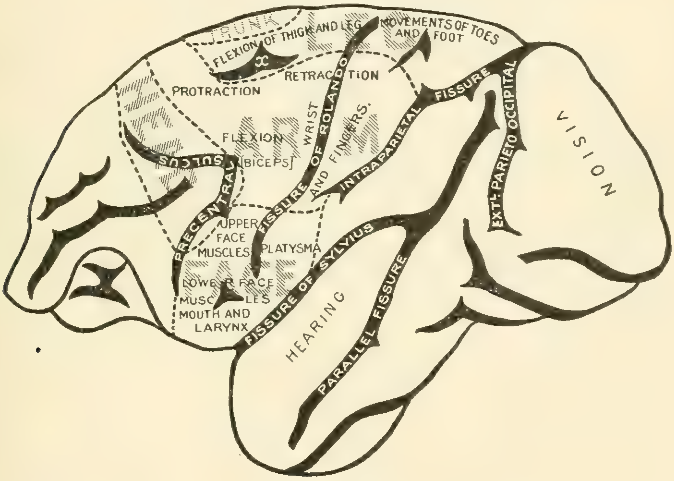
TRUNK
FLEXION OF THIGH AND LEG
MOVEMENTS OF TOES AND FOOT
LEG
RETRACTION
PROTRACTION
FLEXION
(BICEPS)
ARM
WRIST
FISSURE OF ROLANDO
AND FINGERS.
INTRAPARIETAL FISSURE
EXT. PARIETO OCCIPITAL
VISION
SULCUS
PRECENTRAL
UPPER FACE MUSCLES
PLATYSMA
FACE
LOWER FACE MUSCLES
MOUTH AND LARYNX
FISSURE OF SYLVIUS
HEARING
PARALLEL FISSURE

FIG. 249.—DIAGRAM OF THE MOTOR AND SENSOR AREAS ON THE LATERAL SURFACE OF THE MONKEY BRAIN.—(*After Horsley and Schäfer.*)

The *tactile area* or *area of tactile perception* has not been accurately or definitely located. Ferrier assigned it to the hippocampal region. Schäfer and Horsley assigned it to the limbic lobe, and especially to that portion known as the gyrus fornicatus, as destruction of this convolution was followed by hemianesthesia of the opposite side of the body which was more or less marked and persistent. These observers conclude that the limbic lobe "is largely if not exclusively concerned in the appreciation of sensation, painful and tactile." Other experimenters question this conclusion and locate the area near to, if not within, the Rolandic area. The difference of opinion regarding the location and probable limitation of the area of tactile sensibility renders necessary additional and more conclusive experiments.

The *olfactory* and *gustatory areas* or *areas of olfactory and gustatory* perception have been located in the uncinate gyrus and the adjacent region, though their exact limits have not been determined by the experiments thus far performed.

The *auditory area* or *area of auditory perception* was located by Ferrier in the upper two-thirds of the superior temporo-sphenoidal convolution. Bilateral cauterization of this region gave rise to complete deafness, which endured to the time of the animal's death, more than a year later. Unilateral destruction of this region gave rise to deafness in the opposite ear only. The results of experiments made subsequently by other observers would indicate that the auditory area is somewhat more extended than that designated by Ferrier, as apparently animals recovered their hearing, to some extent at least, after complete recovery from the operation. The limit or extension of the area is, however, uncertain.

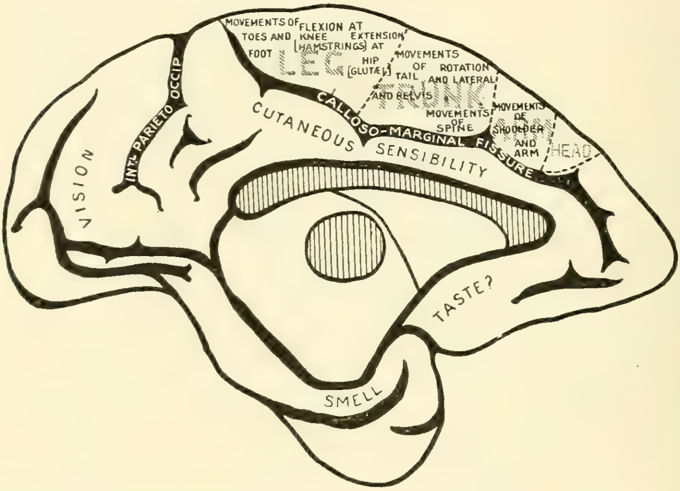
MOVEMENTS OF TOES AND FOOT
FLEXION AT KNEE [HAMSTRINGS]
EXTENSION AT HIP [GLUTÆI]
LEG
MOVEMENTS OF TAIL AND PELVIS
ROTATION AND LATERAL MOVEMENTS OF SPINE
TRUNK
MOVEMENTS OF SHOULDER AND ARM
ARM
HEAD
CALLOSO-MARGINAL FISSURE
CUTANEOUS SENSIBILITY
INT. PARIETO OCCIP.
VISION
TASTE?
SMELL

FIG. 250.—DIAGRAM OF THE MOTOR AND SENSOR AREAS ON THE MESIAL SURFACE OF THE MONKEY BRAIN.—(*After Horsley and Schäfer.*)

The *visual area* or *area of visual perception* has been located in the occipital lobe, though in this, as in the previous instances, its exact limits have not been positively determined. Experimenters also are not in accord as to the relative functions of its different parts. Ferrier located this area in the occipital lobe and that adjacent portion of the parietal lobe on the outer surface known as the angular gyrus. He found that extirpation of the angular gyrus alone was followed by a temporary blindness of the opposite eye, which was, however, not hemiopic in character.* He also found that destruction of the occipital lobe together with the angular gyrus gave rise to a more or less enduring hemianopsia, in addition to the transient blindness of the opposite eye. From these and similar facts he concluded that the angular gyrus is the area of representation for the macular or central region of the retina, and the occipital lobe for the corresponding halves of the peripheral portions of the retina.

It was, however, found by Munk, Schäfer, and others that the angular gyrus was not concerned in any way with vision; that extirpation of the occipital lobe alone, especially if the line of division be carried a little further forward on the mesial and inferior surfaces, was followed by homonymous hemiopia (loss of retinal function on the same side), and therefore homonymous hemianopsia. Additional experiments lead to the conclusion that the area for macular vision is near the anterior extremity of the calcarine fissure, while the area for peripheral vision is in the posterior portion of the mesial surface and for a variable distance on the outer surface. Moreover, there is reason to believe that the area for macular vision is in relation with homonymous halves of the two maculæ luteæ. The supposed error, the assignment of macular vision to the angular gyrus, has been attributed to destruction of the fibers of the optic radiation, which in their course to the occipital lobe pass close to this gyrus.

The Motor Areas of the Monkey Brain.—From experiments made on the brains of monkeys Ferrier mapped out a number of areas stimulation of which give rise to muscle contractions on the opposite side of the body which are so purposive and coördinate in character that they may be regarded as identical with those produced volitionally. Destruction of these areas is followed by paralysis. The results of Ferrier's earlier work are represented in Fig. 251, the descriptive text to which renders them intelligible. In a general way it may be said that the upper third of the anterior and posterior central convolutions presides over the movements of the leg of the opposite side of the body;

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* In a consideration of this subject certain facts connected with visual perception, both in physiologic and pathologic conditions, must be kept in mind. Thus, visual sensation may arise from stimulation of either the central portion, the macula, or the peripheral portion of the retina or both. In the first instance the vision is termed central or macular; in the second instance, peripheral or retinal. Macular vision is clear, sharp, and distinct; retinal vision progressively indistinct from the center toward the periphery. Division of one optic tract is followed, in consequence of the partial decussation of the optic nerve-fibers at the chiasma, by a loss of function in the outer two-thirds of the retina of the same side, both in the central (macular) as well as in its peripheral portions, and the inner one-third of the retina of the opposite side. To this condition the term hemiopia has been applied. As a result of this want of functional activity of these retinal portions on the side of the lesion, rays of light emanating from objects situated in the *opposite side* of the *field of vision* will not be perceived when both eyes are directed to the fixation point. To this "blindness" in the opposite half of the field of vision the name hemianopsia is given. In the lesion under consideration (division of one optic tract) the hemianopsia is *bilateral*, and as it affects the corresponding portions associated in normal vision it is of the *homonymous* variety. Division of the right optic tract is followed by *left lateral homonymous hemianopsia*, indicative of the fact that objects in the field of vision to the left of the binocular fixation point are invisible.

the middle third over the movements of the arm; the inferior third over the movements of the face and tongue. Collectively these areas are known as the *motor area* or *motor zone;* and as it is ranged along the Rolandic fissure, it is sometimes termed the *Rolandic area.*

The experiments of Horsley and Schäfer added additional facts and enabled them to construct a new diagrammatic representation of the motor area and more accurately define the special areas upon the lateral and mesial aspects of the brain of the monkey. The boundaries of the general and special areas, as determined by these observers, will be readily apparent from an examination of Fig. 249. Their experiments have enabled them also to subdivide the general into special areas as follows:

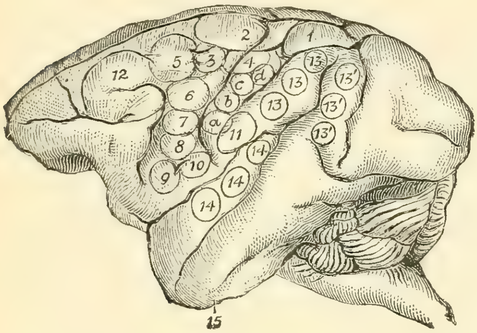

Fig. 251.—Left Hemisphere of Monkey, Showing Details of Motor Areas Indicated by the Movements Following Stimulation of: 1. Superior parietal lobule; exciting advance of the hind limb. 2. Top of ascending frontal and parietal convolutions; flexion and outward rotation of thigh; flexion of toes. 3. On ascending frontal convolution near semilunar sulcus; movements of hind limb, tail and extremity of trunk. 4. On adjacent margins of ascending frontal and parietal convolution; adduction and extension of arm, pronation of hand. 5. Top of ascending frontal near superior frontal convolution; forward extension of arm. *a*, *b*, *c*, *d*. On ascending parietal; movements of various muscles of the forearm. 6. Ascending frontal convolution; flexion of forearm and supination of hand which is brought toward mouth. 7. Retraction and elevation of corner of mouth. 8. Elevation of nose and lip. 9 and 10. Opening mouth and motions of tongue. 11. Retraction of angle of mouth. 12. Middle and superior frontal convolutions; movements of head and eyelids. 13 and 13'. Anterior and posterior limbs of angular gyrus; movements of eyeballs. 14. Superior temporo-sphenoidal convolution, ear pricked and head moved. 15 Movement of lip and nostril.—(*Ferrier.*)

1. The *head area* or *area for visual direction* into areas excitation of which causes "opening of the eyes, dilatation of the pupils and turning the head to the opposite side with conjugate deviation of the eyes to that side."
2. The *leg area* may be subdivided into (*a*) an area both on the lateral and mesial surfaces which presides over the movements of the hip and thigh; (*b*) an area in the posterior part which presides over the movements of the legs and toes; (*c*) an area in the paracentral lobule for the movements of the hallux or great toe.
3. The *trunk area*, situated largely on the mesial surface, may be subdivided into an anterior and a posterior area, which respectively preside over the movements of the spinal column as arching and rotation, and the movements of the pelvis and tail.
4. The *arm area* may be subdivided as follows: (*a*) an area superiorly

which controls the movements of the shoulder; (*b*) an area posteriorly and below this, which controls the movements of the elbow; (*c*) an area anteriorly and below the preceding, governing the movements of the wrist and fingers; (*d*) an area posteriorly and below governing the movements of the thumb.

5. The *face area* may be divided into an upper part, comprising about one-third, and a lower part, comprising the remaining two-thirds. In the upper part are areas governing the movements of the opposite angle of the mouth and of the lower face. In the lower part anteriorly there is an area governing the movements of the vocal membranes or bands (the laryngeal area); posteriorly areas governing the opening and closing of the mouth, the protrusion and retraction of the tongue.

Electric stimulation of the sensor areas is attended by certain motor reactions which vary in accordance with the area stimulated. Thus, when the electrodes are applied to different portions of the occipital lobe the eyeballs are conjugately turned upward, downward, or laterally and to the opposite side; when placed on the upper portion of the superior temporal convolution, the ear is pricked up or retracted, the head is turned to the opposite side and the pupils are dilated; when placed on the hippocampal convolution, there is movement of torsion of the nostril and lips of the same side.

Ferrier assumed that these movements were the result of the origination of subjective sensations and not an evidencet that the area in question is a motor area, in the sense that this term is applied to the areas of the Rolandic region, especially as their destruction is not followed by paralysis of any of the corresponding muscles. This interpretation is supported by the experiments of Schäfer, which showed that the contraction of the eye-muscles which followed stimulation of the occipital lobe took place between 0.2 and 0.3 second later than when the frontal lobe was stimulated; and that as the motor reaction takes place after extirpation of the frontal region, the route of the efferent impulse cannot be to and through the frontal lobe, but probably through some lower center. The same facts hold true for the reactions of the ear-muscles following stimulation of the temporal lobe.

The view that the cortex of the cerebrum can be divided into separate and independent though physiologically related motor and sensor areas has been questioned in recent years, and a somewhat different interpretation given to the facts. It is believed by many physiologists and neurologists that the so-called motor and sensor areas are so closely related that it is almost impossible to distinguish one from the other either anatomically or physiologically. Thus the Rolandic region is believed to be both motor and sensor in function, the former, however, being more predominant in the pre-central, the latter in the post-central, convolution. As these two functions are so intimately blended and their anatomic substrata so difficult of separation, it is thought the term *sensori-motor* should be employed as more descriptive and more in accordance with the facts to the entire Rolandic region.

This view has been strengthened by the results of the embryologic investigation of Flechsig, which show that different nerve-tracts become medullated or receive their myelin investment at successively later periods and that the tracts which first become myelinated and are hence first functionally active, belong to the afferent system. Among the first to undergo myelinization are three tracts numbered by Flechsig 1, 2 and 3, which arise largely from the median nucleus of the thalamus and the medial lemniscus and pass to the anterior and posterior convolutions, to the para-central lobule and foot of the superior frontal convolution, and to the foot of the third frontal convolution respectively. It is these fibers which convey nerve impulses to the cortex and furnish information regarding changes taking place in the body itself and thus lead to the performance of muscle movements. This area is therefore primarily a sensor area, an area for body-feelings, cutaneous, tactile, muscle, and visceral, and secondarily a motor area. The afferent fibers to this region become myelinated during the ninth month of intra-uterine life, the efferent fibers from it become myelinated during the third month of extra-uterine life.

By the same method of reasoning the gustatory, olfactory, auditory, and visual sense areas are to be regarded as sensori-motor in character, for embryologic investigations show that subsequently to the myelinization of the afferent tracts connecting the sense-organs with the cortex, efferent nerve-tracts arise from or near to the same centers and undergo myelinization. In other words, these areas are primarily sensor and secondarily motor, and therefore should be termed sensori-motor. In Flechsig's own terminology each cortico-petal or afferent tract is accompanied by a cortico-fugal or efferent tract.

In this view sensations, or the mental processes the outcome of sensations, are the immediate cause of the movements of the muscles connected with both the sense-organs and skeletal structures. Though this interpretation—viz., the coincidence of sensor and motor areas—appears more in accordance with the facts than the earlier view, it must be admitted that there are many facts both of a physiologic and pathologic character which it is difficult to harmonize with it.

The Motor Area of the Chimpanzee Brain.—In a series of experiments made by Sherrington and Grünbaum on the brain of the chimpanzee it was discovered that the so-called motor area was not so widely distributed as in the monkeys generally, but was confined almost exclusively to the convolution just in front of the fissure of Rolando, as it was impossible to obtain any movement on direct stimulation of the convolution just behind it. All points on the surface of the pre-central convolution, including the portion forming the wall of the Rolandic fissure itself, were found to be excitable and productive of movement when stimulated. The sequence of representation from below upward is similar to that observed in the monkey. One peculiarity, however, was the location of the area for conjugate deviation of the eyeballs to the opposite side. This is situated far forward in the middle and inferior frontal convolutions, and separated from the areas in the pre-central convolution by a region apparently inexcitable. These facts are of great interest and value in the assignment of the motor areas in the cortex of the human brain, as in its development and configuration the chimpanzee brain more closely resembles the human brain than does the monkey's.

The Localization of Sensor and Motor Areas in the Human Brain.—The observation of clinical symptoms and their interpretation by postmortem findings, the phenomena observed during surgical procedures, and the results of embryologic investigations, point to the conclusion that corresponding areas both for sensations and movements exist in the cerebral cortex of the human brain, though it is probable that their locations do not in all respects coincide with those characteristic of the monkey or even the ape brain. In the following diagrams (Figs. 252 and 253), the sensor and motor areas are at least provisionally located, in accordance with recent observations. They are represented as limited or bounded by a serrated line to indicate, as suggested by Mills, that they are not sharply defined, but that they interfuse or interdigitate with surrounding regions.

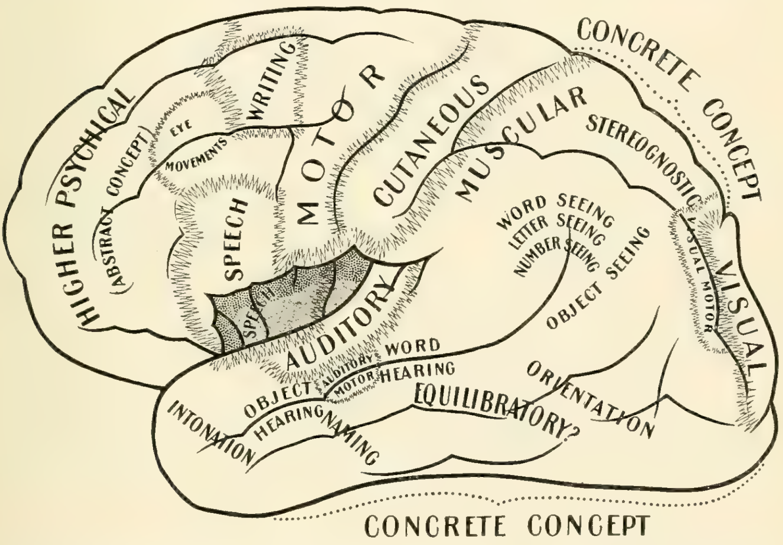
HIGHER PSYCHICAL
(ABSTRACT CONCEPT)
EYE
MOVEMENTS
WRITING
SPEECH
MOTOR
CUTANEOUS
MUSCULAR
CONCRETE CONCEPT
STEREOGNOSTIC
WORD SEEING
LETTER SEEING
NUMBER SEEING
OBJECT SEEING
VISUAL MOTOR
VISUAL
SPEECH
AUDITORY
WORD
HEARING
AUDITORY
MOTOR
OBJECT
HEARING
NAMING
INTONATION
EQUILIBRATORY?
ORIENTATION
CONCRETE CONCEPT

Fig. 252.—The Areas and Centers of the Lateral Aspect of the Human Hemicerebrum.—(*C. K. Mills.*)

The Sensor Areas.—The sensor areas occupy regions corresponding in a general way with those of the monkey brain.

The *cutaneous and muscle sense areas* have been assigned to the post-central, a portion of the super and sub-parietal convolutions on the lateral aspect, and to portions of the frontal convolution and of the callosal convolution on the mesial aspect. It is also probable that the tactile (cutaneous) area may be assigned, though in less degree, to the pre-central convolution, the general motor area. This is in accordance with the embryologic investigations of Flechsig, who concludes that the entire Rolandic region is to be regarded as sensor as well as motor in function, and names it the area of body feelings, or the somesthetic area.

The clinic and postmortem evidence as to the extent of the area of tactile sensibility and its coincidence with the motor area is somewhat contradictory, and in some respects apparently in opposition to the view of Flechsig. Thus, Dr. C. K. Mills, whose skill in interpreting the phenomena of disease is well known, states in this connection in his work on nervous diseases that "innumerable cases have been reported of lesions of the motor cortex without the slightest impairment of sensibility." In several cases of excision of the human cortex in the Rolandic region by surgical operations careful studies of the patients failed to show any impairment of sensation. Other competent observers, however, have reported a number of cases in which anesthesia more or less pronounced and persistent has accompanied lesions of the motor area. The explanation of these contradictory observations is not apparent.

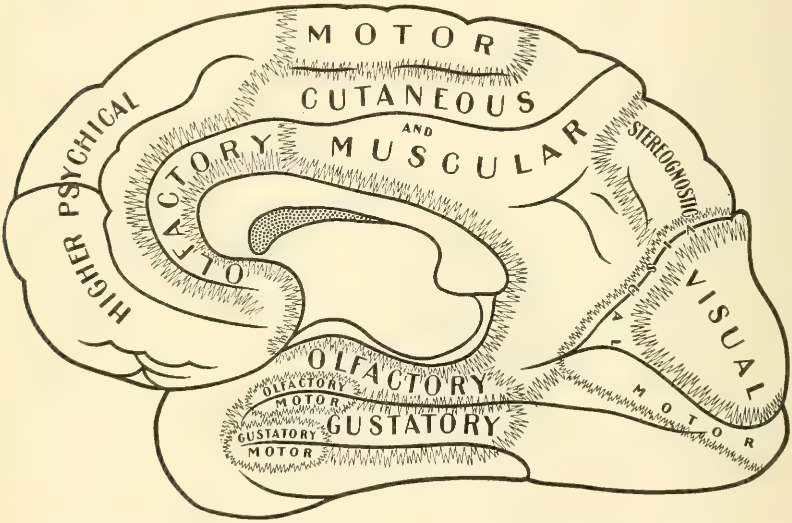

FIG. 253.—THE AREAS AND CENTERS OF THE MESIAL ASPECT OF THE HUMAN HEMICEREBRUM.—(*C. K. Mills.*)

The *olfactory area* has been assigned to the uncinate convolution, the anterior part of the callosal convolution, and the posterior part of the base of the frontal lobe. Lesions in this region are frequently accompanied by subjective olfactory sensations.

The *gustatory area* has been assigned to the collateral convolution.

The *auditory area* has been assigned to the posterior portion of the super temporal convolution and to the retro-insular convolutions, the island of Reil. Unilateral destruction of this region is followed by only a partial loss of hearing in the opposite ear (owing to the partial decussation of the cochlear nerve), which, however, may be recovered from after a time, owing probably to a compensatory activity of the insular convolutions. Bilateral disease of this region is followed by complete deafness. Within this area there is a smaller region, disease of which is accompanied by *word-deafness* only, the patient being unable to distinguish the tone intervals between words and syllables and therefore hearing only confused noises. Object hearing has also a separate area of representation.

The *visual area* has been assigned to a triangular shaped area on the mesal surface of the occipital lobe, which includes the gray matter above and below the calcarine fissure (the cuneus and upper part of the lingual lobe), and to the gray matter of the first occipital convolution on the lateral aspect of the occipital lobe. Focal lesions of this area on one side are followed by lateral homonymous hemianopsia, which, however, does not involve, as a rule, the fovea or macula. It is, therefore, the area of homonymous half-retinal representation. The location of the area for macular or central vision is uncertain. Henschen locates it in the anterior part of the area near the extremity of the calcarine fissure, and asserts that in each area both maculæ are represented. From experiments made on monkeys Schäfer locates it in the same region. Beyond the limits of this visual area and on the lateral aspect of the parietal lobe there is a region (the supra-marginal convolution and angular gyrus) in which impressions of words and letters seen have their representation. Destruction of this area by diseases is followed by *word-* and perhaps *letter-blindness*, the patient being unable to recognize words and letters seen because of failure to revive the memory images of words and letters. The areas for visual sensations and optic memory pictures are therefore separate, a fact which has led to a division of the visual area into a lower and a higher area.

It was stated in a previous paragraph that electric stimulation of the sensor areas of the monkey brain is attended by certain motor reactions which vary with the area stimulated. Corresponding areas are believed to be present in the human brain and that their stimulation would be followed by similar motor reactions. Their location is shown in Figs. 252 and 253, and named visual, auditory, olfactory, and gustatory motor.

The *stereognostic area* or *area of stereognostic perception*, by which objects are recognized through their form independent of vision and by the sense of touch alone, has been located in the super parietal convolution and the precuneus (Mills). The existence of such an area is rendered probable by the fact that cases have been recorded in which there was a loss of this power (astereognosis) uaccompanied by either sensor or motor disturbances. Postmortem investigations showed that in these cases there was a destruction of the superior parietal convolution.

Equilibratory, intonation, and orientation areas have been provisionally located in the sphenotemporal lobe.

The Motor Area.—The general motor area (Fig. 254) is represented as occupying the pre-central convolution, the base of the super-frontal convolution, both on its lateral and mesial aspects, and the paracentral lobule. The exclusion of the post-central convolution from the motor area is in accordance with the embryologic researches of Flechsig, which indicate that the efferent fibers which compose the pyramidal tract come from the region anterior to the central fissure, and with the experiments of Sherrington and Grünbaum on the brain of the chimpanzee, which demonstrate that the post-central convolution is absolutely inexcitable to electric stimulation. It is quite probable that with the growth of the brain in size and complexity, the motor area has come to occupy a position somewhat farther forward in the human brain than in the monkey brain.

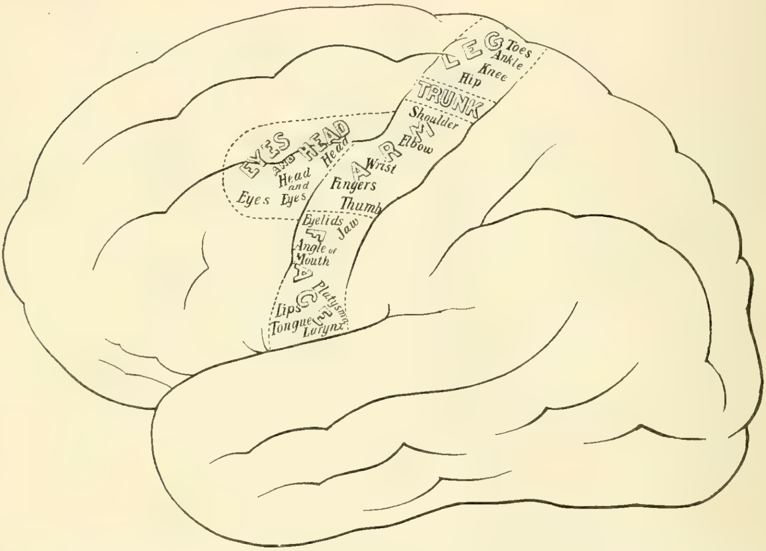

FIG. 254.—SCHEME OF THE MOTOR AREA OF THE HUMAN BRAIN AND ITS SUBDIVISIONS. —(*After Mills.*)

This general area is also capable of subdivision into areas of variable size, in which the movements of the face and associated structures, the head and eyes, the arm, trunk, and leg, are represented. (Fig. 254.) The sequence of their representation from below upward is similar to that observed in the monkey and chimpanzee. In each of these five main areas there are yet smaller areas in which the movements of localized regions of the body are in part represented and which are indicated in diagram (Fig. 254) by corresponding words. The words in the areas marked, eyes and head, face, arm, trunk, and leg, indicate the location of nerve-cells which through the discharge of nerve impulses excite to contraction the muscles, which impart to the regions indicated by these words, their characteristic movements. A *localized irritative lesion* of any one of these areas gives rise to convulsive movements of the muscles of the opposite side of the body, similar in character to those resulting from electric stimulation of the corresponding areas of the monkey and ape brains. *Destruction* of these areas from the growth of tumors, softening, etc., is followed by paralysis of the muscles. Electric stimulation of these areas of the human brain for the purpose of localizing obscure irritative lesions prior to surgical procedures on the brain gives rise to the same convulsive movements.

Language.—The succession of motor acts by which ideas are expressed, is known as language, which may be divided into (1) articulate or spoken, and (2) written.

The expression of ideas both by words and signs depends primarily on the power of reviving the images or memories of words and letters heard and seen; and secondarily on the power of reviving the images or memories of the muscle movements which were previously employed in an effort to imitate or reproduce the words (speech) or the verbal signs (writing).

Clinico-pathologic investigations have shown that words and letters heard and seen have areas of representation in the cortex, the former in the general auditory area, the latter in the supra-marginal convolution and angular gyrus (Fig. 252). Destruction of these areas is followed by *word-deafness* and *word-blindness* respectively. The same methods of investigation have shown that the muscle movements employed to reproduce the words and the verbal signs also have areas of representation in the cortex; the former in the *sub-frontal convolution* (Fig. 252), and probably in the adjacent region, the island of Reil, on the left side in the great majority of people; the latter in front of the arm region of the general motor area. Destruction of these areas is followed in the first instance by a loss of the power of executing the movements of the muscles employed in speech, and in the second instance, of those employed in writing.

These different areas are connected with one another by association fibers, and, taken collectively, constitute the language zone Their situation and relations are shown in Fig. 255. In this figure the dotted lines coming from the ear (a) and the eye (v) represent the auditory and visual tracts through which nerve impulses pass to the auditory (A) and the visual centers (V) respectively. Similar lines coming from the muscles involved in speech and writing might also be represented to indicate the paths of the nerve impulses to the motor speech (M) and the motor writing center (E). The continuous lines on the surface of the cortex represent nerve-fibers which associate the auditory and visual centers with the speech and writing centers and with higher psychic centers (O O) as well. The dotted lines coming from the speech and writing centers represent the tracts through which nerve impulses pass to the muscle of the larynx, tongue, mouth, and lips, and to the muscles of the hand. The anatomic and physiologic association of the various areas is essential to the registration of the impressions made on the ear and eye and for the expression of the ideas evolved from them by words (speech) and signs (writing). Their collective action is essential to the acquisition of language. Destruction of any part of this cerebral mechanism is attended by an impairment or a total loss either in the power of obtaining auditory images of words heard and visual images of words seen, or in the power of expressing ideas by speech and writing. To this pathologic condition the term aphasia has been given.

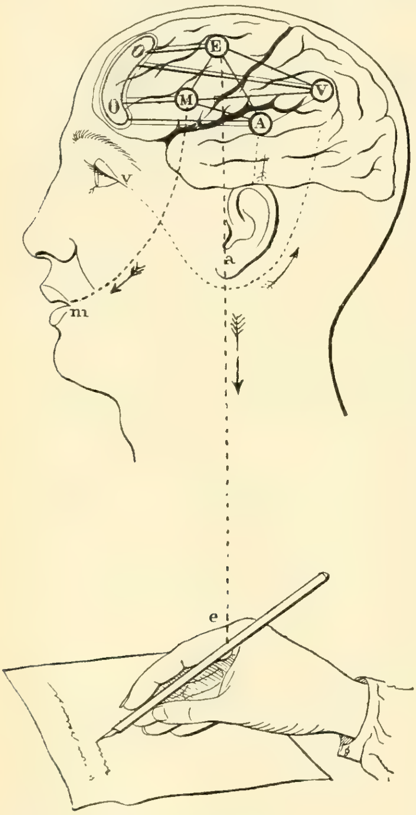

FIG. 255.—DIAGRAM SHOWING THE RELATION OF THE CENTERS OF LANGUAGE AND THEIR PRINCIPAL ASSOCIATIONS. A. Auditory center. V. Visual center. M. Motor speech center. E. Motor writing center. O O. Intellectual center.—(*After Grasset.*)

Aphasia.—It was discovered by Bouillaud that a destructive lesion of the third frontal convolution on the left side was accompanied by a partial or complete loss of the faculty of articulate speech, the power to express ideas with words. To this condition the term *aphasia* was given. Though of limited application etymologically, the word is now employed in a wider sense to signify "partial or complete loss of the power of expression or comprehension of the conventional signs of language," words either spoken or written, due to lesions of different portions of the cortex, and especially on the left side.

Aphasias are of many degrees and kinds, though they may be included in the two general divisions, *motor* and *sensor*.

Motor aphasia may be either ataxic or agraphic. In *ataxic* aphasia the patient is unable to express or communicate his thoughts by spoken words, owing to an inability to execute those movements of the mouth, tongue, etc., necessary for speech without there being any paralysis of these muscles. The lesion is usually in the third frontal convolution and most frequently associated with right hemiplegia. In *agraphic* aphasia the patient is unable to communicate his ideas by writing through an inability to execute the necessary movements, though retaining his mental processes. In this form of aphasia the lesion is in the writing area. These two forms of motor aphasia are not infrequently associated.

Sensor aphasia or amnesia may be either visual or auditory. In *visual* aphasia or amnesia the patient is unable to recognize a letter or word, printed or written (though capable of seeing other objects), a condition known as *letter-* or *word-blindness*. It is usually associated with lesions in the neighborhood of the supra-marginal convolution. In *auditory* aphasia or amnesia the patient cannot understand articulate or vocal speech, though capable of hearing and understanding other sounds, through an inability to distinguish tone intervals of words and letters—a condition known as *word-deafness*. It is associated with lesions of the auditory area.

Paraphasia is an inability to recall the proper words to associate with ideas and necessary to their expression.

Concept aphasia is the inability to recall the names of objects. It is associated with lesions of the cortex of the mid-temporal or third temporal convolution (Mills). This area is known as the *concept* or *naming* area.

Bilateral Representation.—Though highly specialized movements, such as those performed by the arms and hands, legs and feet, have their areas of representation on one side of the cerebrum only, and that, opposite to the side of the movement, less highly specialized movements, such as the masticatory, phonatory, respiratory and various trunkal movements, which require for their performance the coöperation of muscles on both sides of the body, have their areas of representation on both sides of the cerebrum; the area of either side exciting to action the muscles on both sides of the body. In the case of specialized movements the representation is *unilateral;* in the case of the more general movements the representation is *bilateral.*

Association Centers.—The sensor and motor areas to which specific functions have been assigned do not constitute more than one-third of the total cerebral cortex. There yet remain large regions to which it has not been possible to assign specific functions based on physiologic experiments. Three or four such regions separated by the sensor and motor centers are to be recognized on the lateral and mesial aspects of the hemisphere. In Fig. 256 the location, extent, and names of these regions are represented. The fibers which are found in these regions belong almost exclusively to the association system, and become medullated at a later period than do the fibers of the projection system; moreover, from the method of their medullization it would appear that many of these fibers grow out directly from the sensor centers into these regions and become related to the nerve-cells of their convolutions, while others grow out from adjacent as well as distant convolutions. From histologic and pathologic evidence these regions were termed by Flechsig association centers or areas, implying the idea that through the intervention of their cell mechanisms

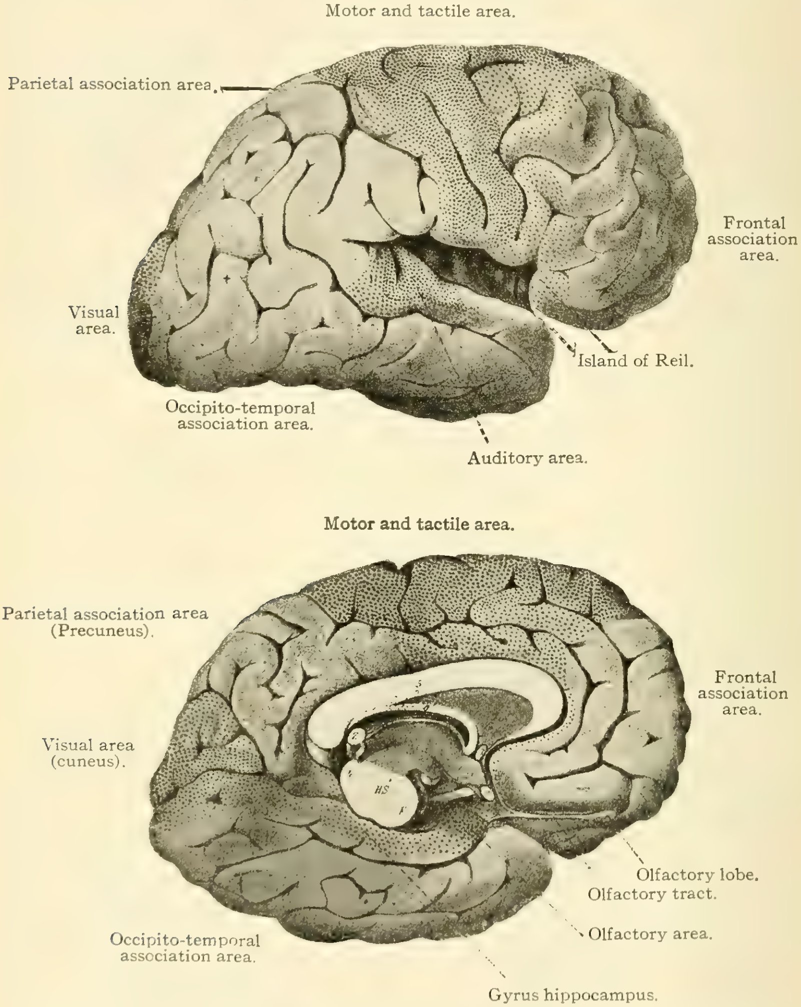
Motor and tactile area.
Parietal association area.
Frontal association area.
Visual area.
Island of Reil.
Occipito-temporal association area.
Auditory area.
Motor and tactile area.
Parietal association area (Precuneus).
Frontal association area.
Visual area (cuneus).
HS
Olfactory lobe.
Olfactory tract.
Olfactory area.
Occipito-temporal association area.
Gyrus hippocampus.

FIG. 256.—DIAGRAMS TO SHOW THE POSITION AND THE RELATION OF THE ASSOCIATION AND PROJECTION AREAS. THE PROJECTION AREAS ARE DOTTED.—(*After Flechsig.*)

the sense areas are indirectly associated anatomically and physiologically, and together constitute a mechanism by which sensations are associated and elaborated into concrete forms of knowledge or related to definite forms of movement.

It has been assumed by Flechsig that the *frontal association* center, from its connections with the sensor and motor areas of the Rolandic region, the olfactory, and perhaps other regions, is engaged in associating and registering body sensations and volitional acts, and that the knowledge thus gained has reference largely to the personality of the individual; that the *parieto-occipital* association area, from its relation to the visual, auditory, and tactile sense areas, is engaged in associating and registering visual, auditory, and tactile sensations, and that the knowledge thus gained has reference mainly to the external world. These assumptions in a general way are supported by the phenomena of disease. In certain lesions of the frontal lobe the symptoms indicate a loss or change of ideas regarding personality rather than of the objective world, while the reverse is true in disease of the parieto-occipital lobe.

The Intra-cranial Circulation.—The circulation within the cranium presents certain peculiarities which distinguish it from that in other parts of the body. These peculiarities reside in part in the anatomic arrangement of the blood-vessels, in the probable absence of vaso-motor nerves to the blood-vessels, and in greater part in the fact that the brain and its blood-vessels are contained in a box with rigid, unyielding and closed walls.

The Blood-supply.—As stated in a previous paragraph the arteries supplying the brain with blood are four in number viz.: The two internal carotids and the two vertebrals. These four arteries anastomose very freely at the base of the brain, the anastomosis constituting the circle of Willis. From this circle there arise the anterior, middle and posterior cerebral arteries which are distributed to the cortex and the underlying white matter. The basal ganglia, the capsule and adjacent white matter are supplied by a number of branches which arise from the circle of Willis or from the three cerebral arteries immediately after their origin. From the distribution of these two sets of vessels they have been named the cortical and the central ganglionic respectively.

The venous blood is returned by a system of vessels which present characteristics of physiologic interest. These vessels consist of large sinuses formed by folds of the dura mater or, as at the base of the cranium, by the dura mater and the bone. These sinuses, from the very nature of the tissues which enter into their formation, have rigid walls and will therefore withstand any pressure to which they may be subjected under physiologic conditions. The same obtains at their points of exit from the cranium where a free outflow is in consequence always assured.

The various sinuses have opening into them, the veins which return the blood from the cortex and subjacent white matter, and from the inner structures of the brain. Neither sinuses nor veins have valves and most of the veins which empty into the superior longitudinal sinus have their mouths directed forward, hence the blood discharged from these veins must flow against the current in the sinus. The venous blood leaves the cranium mainly by way of the internal jugular veins which are direct continuations of the lateral sinuses.

The Intra-cranial Lymph Spaces.—In order to understand the phenomena attending the circulation of blood through the cranium it is necessary to take into consideration an important fact, viz.: that the brain and spinal cord are surrounded on all sides by a relatively large and continuous lymph space. This space which is found between the arachnoid and the pia mater is filled with a liquid, the so-called cerebrospinal fluid, which being interposed between the brain and the skull on the one hand and the spinal cord and the vertebræ on the other hand, acts as a water cushion protecting these delicate organs from the injury which might result from sudden jars. The ventricles of the brain are also filled with cerebrospinal fluid which is in communication with that in the subarachnoid space through the foramen of Magendie and the foramina of Key and Retzius. The cerebrospinal fluid may also penetrate into the perineural lymph spaces surrounding the cranial and spinal nerves. The quantity of the cerebrospinal fluid is relatively small, amounting to from 60 to 80 c.c.

The Mechanism of the Intra-cranial Circulation.—As previously stated, by virtue of the physical relations existing between the blood, the brain, the cerebrospinal fluid and rigid walls of the cranium, the flow of the blood through the brain and cranial cavity, is attended by certain phenomena which are peculiar to this region and present in no other situation.

Taking as a point of departure the conditions during the diastole of the arteries, the relations of these structures are somewhat as follows: the cerebrospinal fluid occupies all the available lymph space, but under a pressure approximately equal to that in the large veins and hence not materially above that of the atmosphere; the pressure in the arteries, capillaries and veins presents the usual values in these different regions of the vascular apparatus; the brain presents a volume which may be termed diastolic.

With the occurrence of the succeeding cardiac systole, the cerebral vessels, receiving an additional volume of blood, expand and occasion a corresponding increase in the volume of the brain, which is accomplished by a partial displacement of the cerebrospinal fluid into extra-cranial lymph spaces. Because of the fact that the displacement of the cerebrospinal fluid is insufficient to permit of the complete expansion of the brain, there is developed in the intra-cranial lymph spaces a counter pressure (the so-called intra-cranial pressure) which would keep pace with and finally equalize the rising pressure in the arteries. In consequence of this, the brain tissue, it is believed, would be subjected to a pressure sufficiently great to interfere with its activities, even to the point of unconsciousness. If this is not to occur the maximum expansion of the arteries, and hence the brain, must be checked and controlled. This is accomplished in the following way: As the brain approaches that degree of expansion permitted by the displacement of the cerebrospinal fluid, it begins to exert a compression of the pial veins. This compression by narrowing the lumen of the veins diminishes their capacity and hence increases the pressure of their contained blood until it is equivalent to the pressure exerted by the brain against the veins. At this moment the pressures in the arterioles, capillaries and veins approximate each other in value.

From these factors it will be seen that the circulation through the brain approximates a circulation through a system of rigid tubes. The result is an increase in the velocity of the outflow and a diminution of the blood-pressure. As an additional result the pulse wave of the arterial system is transmitted to the blood of the large veins and sinuses which therefore exhibit normally pulsations synchronous with those of the arteries. The rise of the pressure in the cerebral veins is regarded therefore as the factor which, by limiting brain expansion, checks the rise of the intra-cranial pressure beyond physiologic limits. With the diastole of the heart and arteries, the former relation of the blood, brain, cerebrospinal fluid and cranial walls is regained. Because of this change of relation with each heart-beat, the brain pulsates synchronously with the arteries.

The brain differs from other organs, also, in that normally its volume is more influenced in a positive direction by the expiratory rise of venous pressure than by the inspiratory rise of general arterial pressure. Thus the rise of pressure in the thoracic veins which occurs with each expiratory act, causes a damming back of the venous blood in the sinuses and pial veins, resulting in a further increase in the volume of the brain and in the intra-cranial pressure. The reverse takes place in inspiration.

It has been ascertained experimentally that the intra-cranial pressure may vary considerably and consciousness still be preserved. Hill found it to be 40 to 50 mm. of Hg. in the convulsions of strychnia poisoning and a little less than zero in a patient standing erect.

The Regulation of the Volume of Blood Entering the Brain.—It is generally believed that the cerebral vessels are not provided with vaso-motor nerves. Every attempt to prove their existence either by physiologic or histologic methods has thus far failed of convincing proof. In the absence of vaso-motor nerves, the regulation of the circulation in the brain must necessarily be dependent on changes affecting the arterial and venous pressures in other regions of the body.

The most effective factor in increasing or decreasing the blood-supply to the brain resides in the power of the vaso-motor center to cause a contraction or dilatation of the cutaneous and splanchnic vessels. Thus if the vaso-motor center declines in its tonus from any cause whatever, there is a relaxation of the blood-vessels in one or both of these regions, an increase in the volume of the blood flowing into them, and in consequence, a decrease in the volume of the blood flowing through the brain. If on the contrary the vaso-motor center is increased in its tonus, the reverse conditions prevail in the cutaneous and splanchnic vessels and the quantity of blood flowing into the brain is increased. Thus in an indirect way the vaso-motor center, by bringing about a rise or a fall in the general arterial pressure, regulates the blood-supply to the brain, and controls its amount in accordance with its needs.

Brain Activity and Brain Repose or Sleep.—Brain activity is characterized by an active consciousness, the development of sensations, ideas, feelings, and the exercise of volitional power (which manifests in muscle movement) and is the result of a physiologic condition of the body at large. For the manifestation of brain activity it is essential, that the irritability of the brain cells and more especially of those composing in large measure the cerebral cortex be maintained at a normal physiologic level, so that they may respond in the manner peculiar to them, to the action of nerve impulses reflected through afferent nerves from all regions of the body. Here as elsewhere throughout the body, the irritability depends on, and is maintained by, the presence of blood flowing into and out of the brain in varying quantity from moment to moment, with a given velocity and under a definite pressure. So long as these conditions are maintained in the strictly physiologic condition, so long will the brain respond to stimuli by the development of sensations. The avenues through which nerve impulses pass to the cortical cells are those beginning in the special and general sense organs of the body in contact with the external world, viz.: the eyes, ears, nose, tongue, and skin. The maintenance of these structures in a strictly physiologic condition is also one of the essential conditions for brain activity.

Judging from the changes in the character and composition of the blood which occur during its passage through the brain capillaries, there is coincidently with brain activity an active metabolism, which eventuates, at the end of a variable number of hours, in the decline of the irritability, a reduction of functional activity, and the establishment of the condition of fatigue. The irritability of the sense organs, especially of the eyes and ears, in all probability declines in a similar manner. These structures pass into the condition of fatigue and become less responsive to external stimuli. The result of all these conditions is a less active stimulation of the brain cells, which in connection with other factors predisposes to

Brain Repose or Sleep.—Brain repose or sleep is characterized by a greater or less degree of unconsciousness, the non-development of sensations, ideas, feelings and volitional acts, and is the result of a diminution in the physiologic activities of the body at large and more especially of the brain, sense organs and spinal cord. Coincident with the cessation of brain activity and the onset of sleep, there is a diminution in the rate and force of the heart beat, and in the frequency and depth of the respiratory movements, and a relaxation of the skeletal muscles, especially those employed in voluntary movements.

The sense organs are in part protected from the action of external stimuli. The eyeball is so turned, that its anterior pole is directed far upward under the eyelid, while the pupil is markedly diminished in size, and in consequence the entrance of light largely prevented. The ear is protected against the reception of sounds of ordinary pitch by an increased tension of the tympanic membrane. The nose and mouth are less responsive to various stimuli because of the dryness of their mucous membranes from diminished secretion. The skin appears to be less sensitive to mechanic pressure and other forms of stimulation.

In addition to the foregoing phenomena, experimental investigations have shown, that there is a shunting of a portion of the blood stream from the brain to other regions of the body, especially to the skin and perhaps to the abdominal viscera as well, whereby it becomes incapable of functionating physiologicly. The fact that the brain receives a lessened quantity of blood during sleep has been shown by trephining the skull and inserting in the orifice a glass plate through which the circulatory conditions of the brain can be observed. In the waking condition the blood-vessels on the surface of the brain are prominent, and turgid with blood and the whole organ completely fills the cranial cavity, indicating that the blood-vessels in the interior of the brain are in a similar condition. With the onset of sleep the larger blood-vessels begin to diminish in size, the smaller vessels disappear from view, the brain tissues become pale and the volume of the brain shrinks. During the continuance of deep sleep, this anemic condition persists. As the period of sleep approaches its termination, the smaller blood-vessels again fill with blood, the surface of the brain flushes, and in a very short time the former circulatory conditions return, the volume of the brain increases and the waking state is reestablished.

The fact that the skin receives an increased volume of blood during sleep, has been shown by inserting an arm or leg in a plethysmograph by which means a record of any change in volume can be obtained. Howell thus succeeded in obtaining graphic records in the variations of the volume of the arm during sleep. These records disclosed the fact that with the onset of sleep the volume of the arm gradually increased in size until it attained a maximum which was from one to two hours after the beginning of sleep. After this period the volume remains practically the same for several hours, diminishing as the intensity of sleep diminishes, and the waking state is approached. Just previous to the return of consciousness there is a rapid diminution in the volume of the arm. If it be accepted that the enlargement of the cutaneous vessels is followed by a diminution in size of the cerebral vessels, it follows that the former condition stands to the latter in the relation of cause and effect, whereby a portion of the blood is diverted from the brain to the skin. It also naturally follows that the withdrawal of the blood from the brain to the skin and possibly other regions as well, is the fundamental condition for brain repose.

The Intensity of Sleep.—Observations of individuals during sleep show, that the intensity or the deepth of sleep varies from hour to hour. Attempts have been made to estimate the intensity by measuring the intensity, or the loudness of a sound caused in several ways, that is necessary to awaken the sleeper. Accepting this criterion it may be stated from the results of many experiments, that sleep increases in intensity or depth and reaches its maximum between the first and second hours, after which it rapidly decreases until the end of the third hour, when consciousness is so nearly restored, that but a very slight stimulus is required to awaken the sleeper. It is during the latter period when the brain is reviving, that dreams arise the element of which are formed of previous sensations.

The Causes of Sleep.—Different theories have been proposed to account for the causes of sleep, none of which have been wholly satisfactory. From all the facts which have been presented it would appear that one cause is a decline in the irritability of the nerve-cells of the brain and associated sense organs, and the development of fatigue conditions, the result of prolonged activity.

A second cause is the withdrawal of a large portion of the blood from the brain on the presence of which, here as elsewhere, normal activity depends. As to whether the diminished activity of the brain is the cause of, or the result of the withdrawal of the blood there has been much difference of opinion. Howell has offered a plausible explanation for the withdrawal of the blood from the brain to the cutaneous vessels, based on the activity of the vaso-motor center. He assumes that for a variable number of hours, corresponding to the usual waking state, this center possesses a certain average tonus, due in all probability to reflex influences, by virtue of which it maintains a certain average contraction of the cutaneous vessels. But at the end of this period it, too, becomes fatigued, declines in irritability, becomes less responsive to reflex influences, and hence loses its control over the vessels. As a result they dilate and thus reduce the amount of blood flowing to the brain to a level insufficient to maintain its activity, after which sleep supervenes. During sleep the irritability and tonus of the center are restored when its control of the blood-vessels is regained. Unless the brain in its functional activities differs from all other organs of the body, it may be inferred that cessation of activity or repose is the result partly of fatigue and partly of a diminution of the blood-supply.

CHAPTER XXII.

THE CEREBELLUM.

The cerebellum is situated in the inferior fossæ of the occipital bone, beneath the posterior lobes of the cerebrum, from which it is separated by the tentorium cerebelli, a semilunar fold of the dura mater. It is partially divided into hemispheres by a longitudinal fissure, more apparent on the inferior surface, though united by a central lobe, the vermiform process. Each hemisphere is connected with the cerebrum, the pons, medulla and spinal cord by three bundles of nerve-fibers known respectively as the *superior*, *middle*, and *inferior peduncles*. The surface of the cerebellum presents a series of lobes and fissures of which the former have received more or less fanciful names. A section of the cerebellum shows that it is composed of gray matter externally and white matter internally. The general appearance presented on section is shown in Fig. 257.

Structure of the Gray Matter.—The gray matter consists mainly of nerve-cells of varying size and shape, which are arranged in two layers: viz., an outer or molecular and an inner or granular.

The molecular layer consists of stellate and multipolar cells of small size, from which dendrites and axons pass horizontally and vertically. The granular layer consists, as its name implies, of granular shaped cells and large stellate cells. These cells are characterized by the possession of dendrites and axons, the course and relation of which have not been clearly determined.

The inner border of the molecular layer presents a series of large cells originally described by Purkinje and known by his name. From the outer end of the cell-body one or more dendrites emerge which soon divide and subdivide into a number of branches which pass toward the cerebellar surface. The general arrangement of these dendrites gives to the entire cell a tree-like appearance (Fig. 258). From the inner end of the cell an axon emerges which passes centrally into the white matter.

Structure of the White Matter.—The white matter consists of nerve-fibers which are arranged in association and projection systems.

The Association System.—The fibers which compose this system are of variable lengths and unite adjacent as well as distant regions of the cerebellar cortex. They doubtless associate them both anatomically and physiologically.

The Projection System.—The fibers composing this system connect the cerebellar cortex with certain structures in the cerebrum, pons, medulla, and spinal cord. They may be divided into efferent and afferent systems.

The *efferent* fibers have their origin in the cells of Purkinje and the dentate nucleus. Some of these fibers emerge from the cerebellum in the superior peduncles through which they pass toward and beneath the corpora quadrigemina to terminate around the cells of the red nucleus. As they approach this nucleus some of the fibers cross the median line and decussate with those coming from the opposite side, while others pursue a straight direction, terminating on the same side. Through the intervention of fibers which arise from the red nucleus and ascend to the cerebral cortex, the cortex is thus connected with both sides of the cerebellum, though chiefly with the opposite side.

Efferent fibers also leave the cerebellum by the middle peduncle and pass directly to the *nucleus pontis*, around the cells of which their terminals arborize. Efferent fibers also descend the inferior peduncles and constitute the tract known as the Löwenthal and Marchi tract, situated in the antero-lateral region of the spinal cord in its upper part.

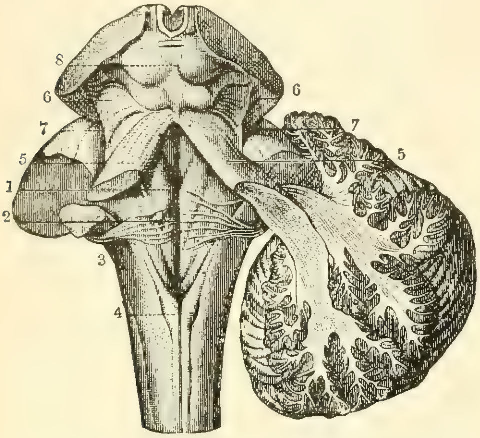

FIG. 257.—VIEW OF CEREBELLUM IN SECTION, AND OF FOURTH VENTRICLE, WITH THE NEIGHBORING PARTS.—(*From Sappey.*) 1. Median groove fourth ventricle, ending below in the calamus scriptorius, with the longitudinal eminences formed by the fasciculi teretes, one on each side. 2. The same groove, at the place where the white streaks of the auditory nerve emerge from it to cross the floor of the ventricle. 3. Inferior peduncle of the cerebellum, formed by the restiform body. 4. Posterior pyramid; above this is the calamus scriptorius. 5, 5. Superior peduncle of cerebellum, or processus e cerebello ad testes. 6, 6. Fillet to the side of the crura cerebri. 7, 7. Lateral grooves of the crura cerebri. 8. Corpora quadrigemina.—(*After Hirschfeld and Leveille.*)

The *afferent* fibers come from a variety of sources. Those found in the superior peduncles come from the red nucleus; those in the middle peduncles from the nucleus pontis of the opposite side, having crossed or decussated at the raphé near the anterior surface of the pons; those contained in the inferior peduncles are the most abundant and important, and are represented by (1) the direct cerebellar tract, which terminates in the superior vermis after decussation; (2) the anterior and posterior arcuate fibers, the former coming from the gracile and cuneate nuclei of the opposite side, the latter from the same side, which also pass to the superior vermis; (3) the acustico-cerebellar tract, composed of fibers the axons of the sensory end nuclei (Deiters) of the vestibular portion of the auditory nerve. It is probable that all these fibers decussate prior to their final termination.

The cerebellum through this system of efferent and afferent fibers is brought into relation with many different regions of the cerebrum, pons, medulla, and spinal cord. Each half of the cerebellum is connected with the foregoing structures of the same side, but more especially of the opposite side.

THE FUNCTIONS OF THE CEREBELLUM.

From the observations of the results of experimental lesions, from analysis of clinico-pathologic facts, and from its comparative anatomic development in different animals, the deduction has been drawn that the cerebellum coördinates and harmonizes the action of those muscles the activities of which are necessary to the maintenance of body equilibrium both during station and progression.

By *equilibrium* of the body is understood a condition which may be maintained for a variable length of time without displacement, and if possible only so long as a line passing through the center of gravity falls within the base of support. The support offered by the earth to the feet neutralizes and counteracts the force of gravity. In station, when the body is in the erect or military position, the arms by the side, the center of gravity lies between the sacrum and the last lumbar vertebra, and the line of gravity falls between the feet and within the base of support. The entire skeleton for the time being is rendered fixed and rigid at all its joints by the combined action of the muscles connected with it. That this position may be maintained all the different groups of antagonistic but coöperative muscles must be accurately coördinated in their actions. Any failure in this respect is at once attended by a disturbance of the equilibrium and displacement.

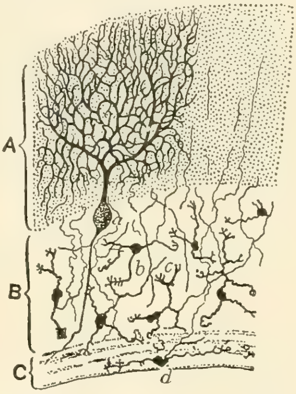

FIG. 258.—SECTION OF CEREBELLAR CORTEX. A. Outer or molecular layer. B. Inner or granular layer. C. White matter. *a.* Cell of Purkinje. *b.* Small cells of inner layer *c.* Dendrites of these cells. *d.* A similar cell lying in the white matter. —(*Stirling.*)

In progression, walking, running, dancing, etc., the body is translated from point to point by the alternate action of the legs. Whether the direction of the translation be linear or curvilinear, as the legs change their position from moment to moment, the center of gravity also changes, and at once the equilibrium is menaced. If it is to be maintained and displacement prevented there must be a prompt readjustment in the relation of all parts of the body so that the line of gravity falls again within the base of support. The more complicated the movements of progression, or the narrower the base of support, the greater is the danger to the equilibrium, and hence the necessity for rapid and compensatory changes in coördinated muscle activity. All movements of this character, in man at least, are primarily volitional and require for their performance the constant exercise of the attention. With frequent repetition they gradually come to be performed independently of consciousness and fall into the category of secondary or acquired reflexes.

Though coördinating power is exhibited by the spinal cord, medulla, and basal ganglia, it is only in the cerebellum that this power attains its highest development and differentiation. To it is assigned the power of selecting and grouping muscles, not in any restricted part, but in all parts of the body, and coördinating their actions in such a manner as to preserve the equilibrium.

The Results of Experimental Lesions.—If the cerebellum in its totality, coördinates and harmonizes the action of the muscles on the opposite sides of the body, any derangement of its structure or its connections with the cord, medulla, pons, or basal ganglia should at once be followed by incoördination of muscles and a want of harmony in their action. Experimental lesions of the cerebellum are attended by such results. The phenomena observed are many and complex. They differ in extent and character in different animals and in accordance with the extent and location of the lesion, though the note of incoördination runs through them all.

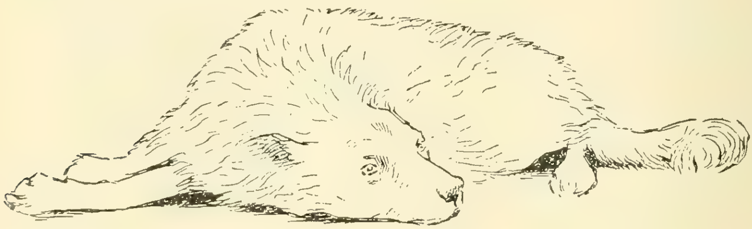

FIG. 259.—ATTITUDE ASSUMED AFTER DESTRUCTION OF THE LEFT HALF OF THE CEREBELLUM.—(*Morat and Doyon, after Thomas.*)

Removal of one lateral half of the cerebellum in the dog is followed by an inability to maintain the equilibrium necessary to the erect position. On attempting to stand, the animal at once falls toward the side of the lesion, the muscles of which at the same time contract and give to the body a distinctly curved condition (Fig. 259). The anterior limbs are extended to the opposite side. On making efforts to regain the standing position, the animal may roll over around the long axis of its body. Conjugate deviation of the eyes is frequently observed as well as nystagmus.

After a few days the symptoms partially subside and the animal acquires the power of sitting on the abdomen when the anterior limbs are widely extended (Fig. 260). As the days go by the improvement continues, and the animal recovers the power of walking, though each step is attended with tremor and oscillations of the body. Any change in the center of gravity such as results when one leg is lifted may result in a fall toward the side of the lesion, owing to an inability to promptly bring about the necessary compensatory muscle actions. With time the animal continues to improve in its power of adjustment, though it never completely recovers it. Movements of progression are apt to be characterized by stiffness and accompanied by tremor suggestive of volitional efforts.

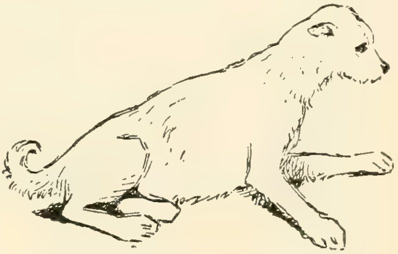

FIG. 260.—ATTITUDE IN REPOSE AFTER THE COMPLETE REMOVAL OF THE CEREBELLUM BUT DURING THE PERIOD OF RESTORATION OF FUNCTION.—(*Morat and Doyon, after Thomas.*)

Total removal of the cerebellum is followed by a different train of symptoms. The extensor muscles apparently preponderate in their action, for the limbs are extended and abducted, the head and neck are retracted, and opisthotonos is established. In time these effects also partially subside, though all attempts at walking are permanently accompanied by tremor and oscillations. The characteristic effect which follows section of the peduncles is again incoördination, manifesting itself in deviation of the head, eyes, inability to walk, tremor on exertion, etc. The effects vary, however, according to the peduncle divided. Section of the middle peduncle gives rise to the most pronounced effects. The head and the anterior part of the body are at once drawn toward the pelvis on the side of the section. A voluntary effort on the part of the animal causes it to lose all control of its muscles and the body is rotated in the direction of its longitudinal axis from 40 to 60 times a minute before it comes to rest. According as the lesion is made from behind or before, the rotation is from or to the side of the section. In time these symptoms subside, though the animal never completely recovers.

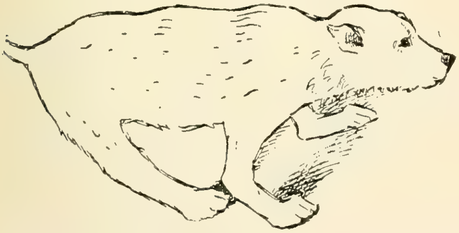

FIG. 261.—PROGRESSION AFTER DESTRUCTION OF THE VERMIS.—(*Morat and Doyon, after Thomas.*)

The partial recovery of the power of coördination, observed after removal of a portion or the whole of the cerebellum, indicates that the centers in the cord, medulla, pons, and cerebrum endowed with corresponding though less developed power, develop compensatory activity and acquire to some extent the capabilities of the cerebellum itself (Fig. 261).

Clinico-pathologic facts partly corroborate the results of physiologic investigations. In various forms of uncomplicated cerebellar disease, vertigo, tremor on making voluntary efforts, difficulty in maintaining the erect position, unsteadiness in walking, opisthotonos, pleurothotonos, are among the symptoms generally observed.

Comparative anatomic investigations reveal a remarkable correspondence between the development of the cerebellum and the complexity of the movements exhibited by animals. In those animals whose movements are complex and require for their performance the coöperation of many groups of muscles the cerebellum attains a much greater development in reference to the rest of the brain than in animals whose movements are relatively simple in character. This relative increase in the development of the cerebellum is found in many animals, such as the kangaroo, the shark, the swallow, and the predaceous birds generally.

The Coordinating Mechanism.—Though it is not known how the cerebellum selects and coördinates groups of muscles for the performance of any complex movement, it is known that its activity is largely reflex in origin and excited by impulses reflected to it from peripheral organs. In this as in other forms of reflex activity the mechanism involves (1) afferent nerves, *e. g.*, cutaneous, muscle, optic, and vestibular, and their related end-organs, tactile corpuscles, muscle spindles, retina, and semicircular canals, all indirectly connected with (2) the cerebellar centers; (3) efferent nerves indirectly connected with (4) the general musculature of the body. Both station and progression are directly dependent on the development and transmission of afferent impulses from the previously mentioned peripheral sense-organs to the cerebellum. Tactile, muscle, visual, and labyrinthine impressions and sensations not only coöperate in the development and organization of the motor adjustments necessary to the maintenance of the equilibrium and locomotive coördination, but even after their organization they are necessary to the excitation of cerebellar activity. The manner in which they lead to the development of this capability on the part of the cerebellum is conjectural. Their ever-present influence is shown by the effects which follow their removal, as the following facts indicate.

The prevention of the development of *tactile* impulses by freezing or anesthetizing the soles of the feet, and the blocking of normally developed impulses through destruction of afferent pathways in diseases of the spinal cord lead at once to marked impairment in the coördinating power. The removal of the skin from the hind legs of the frog, previously deprived of its cerebrum, destroys its coördinating power, which it would otherwise possess in a high degree.

The blocking in consequence of destructive lesions of the spinal cord, of the impulses, which come from the *muscles*, *tendons*, etc., and which inform us of the activity and the degree of activity of our muscles, the location of the limbs, the amount of effort necessary to produce a given movement, etc., also gives rise to much incoördination. A blocking of both tactile and muscle impulses frequently exists in degeneration or sclerosis of the posterior columns of the spinal cord. The coördinating power is so much impaired in this disease that the patient is unable to maintain, without strained effort, the erect position and especially if the directive power of the eyes be removed by closure of the lids. Walking becomes extremely difficult; the gait is irregular and jerky, and equilibrium is maintained only by keeping the eyes fixed on the ground in front and by artificially increasing the basis of support by the use of canes.

An interference with the development of the customary *visual* impressions which in a measure maintain the sense of relation of the individual to surrounding objects also gives rise to equilibratory disturbances. A rapid change in the relation of the individual to surrounding objects or the reverse; a change in the direction of one optic axis from the use of a prism or from paralysis of an eye muscle; the destruction of an eye;—these and similar conditions frequently give rise to such marked disturbances of the equilibratory power that displacement is difficult to prevent.

An interference with the development of the so-called *labyrinthine* impressions by destruction of the semicircular canals gives rise to the most remarkable disturbances in this respect. Section of one horizontal canal* in the pigeon is followed by oscillations of the head in a horizontal plane around a vertical axis. Bilateral section so increases these oscillations that the pigeon is unable to maintain equilibrium and forced to fall and turn continuously around the vertical axis. Bilateral section of the posterior vertical canals gives rise to oscillations around a horizontal axis which frequently become so exaggerated as to eventuate in the turning of backward somersaults, head over heels. Similar phenomena follow division of the superior vertical canals.

Bilateral destruction of both sets of canals is attended by extraordinary disturbances in the equilibrium. From the moment of the operation the animal, the pigeon, loses all control of its motor mechanisms. It can neither maintain a fixed attitude nor execute orderly movements of progression; its activity, continuous and uncontrollable, is characterized by spinning around a vertical axis, turning somersaults, dashing itself against surrounding objects until life is endangered. If the animal be protected from injury, these disturbances gradually subside, and in the course of a few months the equilibratory power is so far regained that standing and walking at least become possible. In this condition, however, the coördinating power is directly dependent on visual impulses, for with the closure of the eyes all the previous motor disturbances at once recur. These and similar facts indicate that the semicircular canals are the peripheral sense-organs from which come the nerve impulses most essential to the excitation of the cerebellar coördinative centers in their control of equilibrium and of progression.

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* The physiologic anatomy of the semicircular canals is described in the chapter devoted to the ear, to which the reader is referred.

The cerebellum may therefore be regarded as the essential, most highly differentiated portion of the coördinating mechanism concerned in the maintenance of equilibrium, during both station and progression. The manner in which the cerebellum accomplishes this result is unknown, though it is certain, from the foregoing facts, that its special mode of activity is dependent on the excitatory action of nerve impulses reflected from a variety of peripheral sense-organs.

CHAPTER XXIII.

THE CRANIAL NERVES.

The nerve-trunks which serve as channels of communication between the encephalon and the structures of the head, the face, and in part the organs of the thorax and abdomen, pass through foramina in the walls of the cranium, and for this reason are termed cranial nerves.

According to the classification now generally adopted, there are twelve cranial nerves on either side of the median line, which, enumerated from before backward, are as follows (Fig. 262):

First or Olfactory.
Second or Optic.
Third or Oculo-motor.
Fourth or Patheticus.
Fifth or Trigeminal.
Sixth or Abducens.
Seventh or Facial.
Eighth or Auditory.
Ninth or Glosso-pharyngeal.
Tenth or Pneumogastric or Vagus.
Eleventh or Spinal Accessory.
Twelfth or Hypoglossal.

The cranial nerves may be classified physiologically in accordance with their functional manifestations into three groups, viz.:

1. Nerves of Special Sense: *e. g.*, Olfactory, Optic, Auditory, Gustatory (Glosso-pharyngeal).
2. Nerves of General Sensibility: *e. g.*, Large root of the Trigeminal, Glosso-pharyngeal, and Pneumogastric.
3. Nerves of Motion: *e. g.*, Oculo-motor, Patheticus, the small root of the Trigeminal, Abducens, Facial, Spinal Accessory, and Hypoglossal.

Though this classification in the main holds true, it must be borne in mind that modern investigations have demonstrated that the glosso-pharyngeal and pneumogastric nerves contain even at their junction with the medulla oblongata a number of efferent or motor fibers, and to this extent are mixed nerves.

The Origins of the Cranial Nerves.—In accordance with modern views as to the origins of nerves in general, it may be stated that—

The *nerves of special sense* have their origin respectively in the neuro-epithelial cells in the mucous membrane of the olfactory region of the nose, in the ganglion cells of the retina, in the cells of the spiral ganglion of the cochlea and the ganglion of Scarpa, and in the cells of the petrous and jugular ganglia. From the cells of these ganglia dendrites pass peripherally to become associated with specialized end-organs, while axons pass centrally in well-defined bundles to become related by means of their end-tufts with primary basal ganglia.

The *nerves of general sensibility* have their origin in the ganglia on their trunks, and in this respect resemble the spinal nerves. From the ganglion cell there emerges a short axon process which soon divides into a central and a peripheral branch. The former passes toward and into the gray matter located beneath the floor of the fourth ventricle, where its end-tufts arborize about nerve-cells. The latter (the peripheral branch) passes toward the general periphery to be distributed to skin and mucous membranes (Fig. 263).

The *nerves of motion* have their origin in the nerve-cells in the gray matter beneath the aqueduct of Sylvius and beneath the floor of the fourth ventricle (Fig. 264). The axons emerging from these cells course peripherally to be distributed to skeletal muscles. In some of the motor nerves, and in some sensory nerves as well, there are to be found efferent fibers of smaller size which have a similar origin and which become related through the intervention of sympathetic ganglia (peripheral neurons) with visceral muscles and glands. These nerves have been termed autonomic nerves.

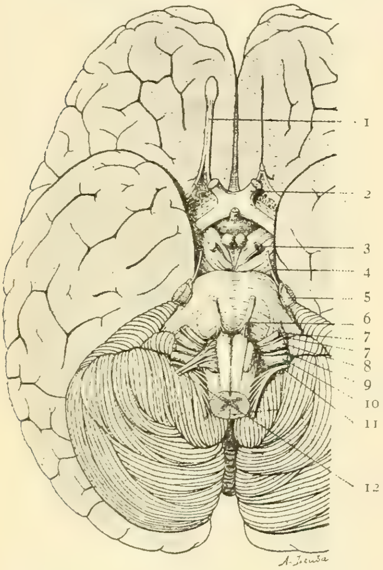

Fig. 262.—Superficial Origin of the Cranial Nerves from the Base of the Encephalon. 1. Olfactory. 2 Optic. 3. Motor oculi. 4. Patheticus. 5. Trigeminal. 6. Abducens. 7. Facial. 7'. Nerve of Wrisberg. 8. Auditory. 9. Glosso-pharyngeal. 10. Pneumogastric. 11. Spinal accessory. 12. Hypoglossal.—(*Morat and Doyon.*)

The Cortical Connections of the Cranial Nerves.—Each of these three groups of cranial nerves has special connections with the cerebral cortex.

The *nerves of special sense* for the most part terminate in primary basal ganglia, around the cells of which their central end-tufts arborize. From these cells axons arise which pass upward and directly or indirectly come into physiologic relation with sensor nerve-cells in the cerebral cortex.

The *nerves of general sensibility* terminate in the gray matter beneath the floor of the fourth ventricle, around the nerve-cells of which their end-tufts arborize. These groups of nerve-cells are known as sensor end-nuclei. Though once regarded as the centers of origin of the sensor nerves, they are now regarded as the centers of origin of axons which pass upward to the cortex of the cerebrum, where they also come into physiologic relation with sensor nerve-cells.

The axons in both of these classes of nerves thus originate in the cells of the central nerve system and continue upward to the cerebrum, the primary afferent path.

The *motor nerves* which have their origin in the cells of the gray matter beneath the aqueduct of Sylvius and beneath the floor of the fourth ventricle are in physiologic relation with nerve-cells in the motor region of the cortex through descending axons contained in the pyramidal tract, the end-tufts of which arborize around the nerve-cells. The efferent path beginning in the cerebral cortex is thus continued by the motor nerves to the general periphery.

The three groups of nerves, those of special sense, of general sensibility, and the motor nerves, are neurons of the first order; the nerve-cells and fibers which constitute the cerebral connections are neurons of the second order. It is probable that the sensor cells in the cerebral cortex are neurons of a third order.

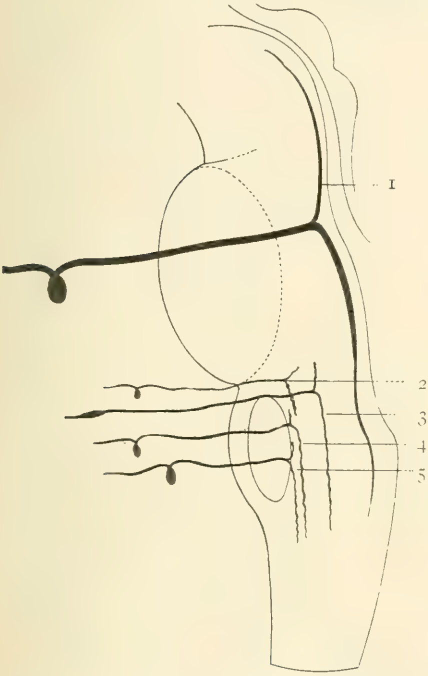

FIG. 263.—GANGLIA OF ORIGIN OF THE SENSOR CRANIAL NERVES. 1. Trigeminal (ganglion of Gasser). 2. Nerve of Wrisberg. 3. Auditory (ganglion of Scarpa). 4. Glosso-pharyngeal (ganglion of Andersch). 5. Pneumogastric (ganglion plexiformis).—(*After Morat and Doyon.*)

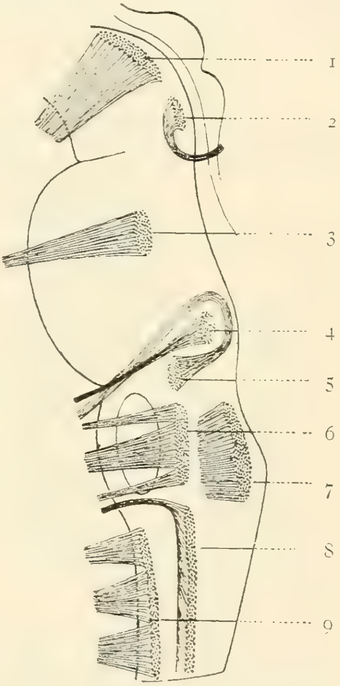

FIG. 264.—NUCLEI OF ORIGIN OF THE MOTOR CRANIAL NERVES. 1. Motor oculi. 2. Patheticus. 3. Motor root of the trigeminal. 4. Abducens. 5. Facial. 6. Mixed nucleus for efferent fibers of the glosso-pharyngeal vagus and spinal accessory. 7. Hypoglossus. 8. Spinal accessory. 9. Spinal nerves.—(*After Morat and Doyon.*)

FIRST PAIR. THE OLFACTORY.

The first cranial nerve, the olfactory, is situated in the upper third of the nasal fossa, in the *regio olfactoria*. It consists of from 20 to 30 branches, the fibers of which are non-medullated.

Origin.—The olfactory nerve is composed of centrally coursing axons which have their origin in the central ends of bipolar, rod-shaped, or spindle-shaped nerve-cells interspersed among the epithelial cells covering the mucous membrane in the regio olfactoria; the peripheral ends of these cells give off a number of dendrites which are spread out to form a delicate feltwork over the surface of the mucous membrane. From their origin the axons gradually converge to form bundles which ascend to the cribriform plate of the ethmoid bone, through the foramina of which they pass to become related by their end-tufts with structures in the gray matter of the olfactory bulb (Fig. 265).

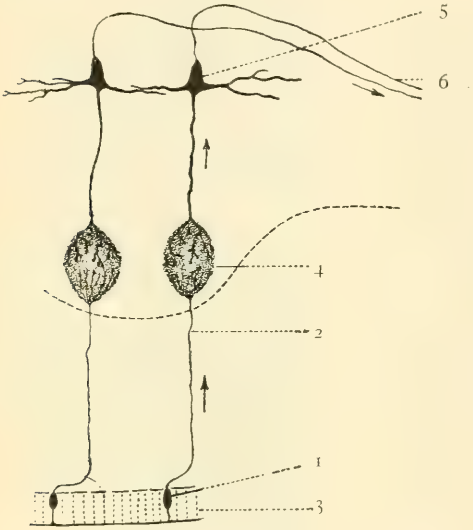

Fig. 265.—The Relation of the Olfactory Nerves to the Olfactory Tract. 1. Olfactory nerve-cell. 2. Axon process. 3. Epithelial cells. 4. Glomerulus. 5. Mitral cells. 6. Centrally coursing axons of the olfactory tract.—(*Morat and Doyon.*)

Cortical Connections.—The olfactory bulb and olfactory tract, formerly called the olfactory nerve, are portions of the cerebrum (the olfactory lobe) which arise embryologically by a protrusion of the walls of the cerebral cavity. The bulb is oval-shaped and consists of both gray and white matter. It rests on the cribriform plate of the ethmoid bone and is embraced by the olfactory nerves. As seen on sagittal section, there is just beneath the surface a layer of large pyramidal and spindle-shaped cells (termed also mitral cells), each provided with an apical and two lateral dendrites. The apical dendrite passes toward the surface and ends in a brush- or basket-like expansion which interlaces with the end-tufts of the olfactory nerves, forming what are known as the olfactory glomerules. The lateral dendrites end free.

The axons of the pyramidal cells pass toward the center of the bulb and bend at right angles, after which they pursue a horizontal direction toward and into the *olfactory tract*. This tract is about five centimeters in length, prismatic in shape on cross-section and divisible into a *ventral* and a *dorsal* portion. It emerges from the posterior extremity of the bulb, passes backward to the posterior part of the anterior lobe, where it divides into three roots: viz., a lateral or external, a mesial or internal, a middle or dorsal. The fibers of the lateral and mesial roots are derived almost exclusively from the *ventral* portion of the tract, the fibers of which come from the mitral cells in the bulb.

The lateral root-fibers pass outward into the fossa of Sylvius and come into relation with nerve-cells in the inferior extremity of the gyrus hippocampus and the gyrus uncinatus. The mesial fibers pass inward and come into relation with nerve-cells in the pre-callosal part at least of the gyrus fornicatus. The fibers thus far considered are undoubtedly true olfactory fibers, pursuing a centripetal direction, carrying nerve impulses from the olfactory cells to the cerebrum (Fig. 266).

Histologic and embryologic methods of research have shown that some of the fibers in the olfactory tract are centrifugal in direction. They originate in the olfactory cortical areas, pass toward the periphery as far as the anterior commissure, where they cross to become the dorsal root, enter the olfactory tract, and finally terminate in the bulb. This tract serves to connect the cortex with the bulb of the opposite side, and carries impulses from the cortex to the bulb. The two opposite cerebral olfactory areas are also united by commissural fibers which decussate at the anterior commissure.

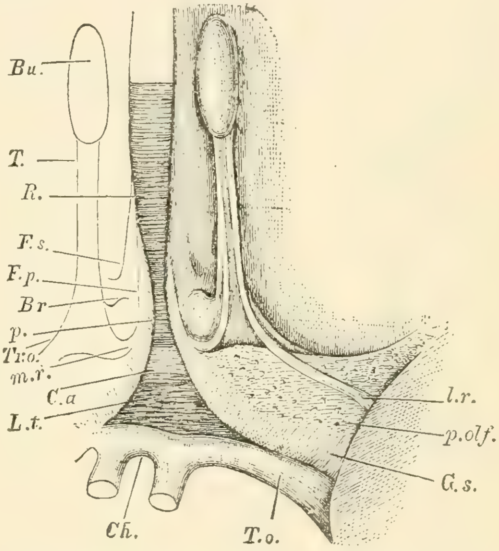

FIG. 266.—OLFACTORY LOBE OF THE HUMAN BRAIN.—*Bu.* Olfactory bulb. *T.* Tract. *Tr.o.* Trigone. *R.* Rostrum of corpus callosum. *p.* Peduncle of corpus callosum, passing into *G. s.*, gyrus subcallosus (diagonal tract, Broca). *Br.* Broca's area. *F.p.* Fissura prima. *F.s.* Fissura serotina. *C.a.* Position of anterior commissure. *L.t.* Lamina terminalis. *Ch.* Optic chiasma. *T.o.* Optic tract. *p. olf.* Posterior olfactory lobule (or anterior perforated space). *m.r.* Mesial root. *l.r.* Lateral root of tract.—(*His.*)—(*After Quain.*)

Function.—The function of the olfactory system in its entirety, is the transmission of nerve impulses from its origin in the olfactory region of the nose to the cerebral cortex, where they evoke sensations of odor. The stimulus to its excitation is the impact and chemic action of gaseous or volatile organic matter on the dendrites of the olfactory cells. The sensitiveness of the olfactory end-organ to the action of many substances is remarkable, responding, for example, to the $\frac{1}{1200000}$ of a gram of oil of roses and to the $\frac{1}{2760000}$ of a gram of mercaptan.

Division or destruction of the olfactory path at any point is followed by an abolition of the sense of smell on the corresponding side. Destructive lesions of the hippocampal and uncinate gyri are followed by similar results.

SECOND PAIR. THE OPTIC.

The second cranial nerve, the optic, consists of centrally coursing axons of neurons, which connect the essential part of the organ of vision, the retina, with sensory end-nuclei or ganglia situated at the base of the cerebrum.

Origin.—The axons which constitute the optic nerve have their origin in the ganglionic cells in the anterior part of the retina. Through their dendrites these cells are brought into relation posteriorly with successive layers of cells which collectively constitute the retina. Though the retina is said to consist of ten or eleven layers, it may be reduced practically to three, viz. (Fig. 267):

1. The layer of visual cells.
2. The layer of bipolar cells.
3. The layer of ganglionic cells.

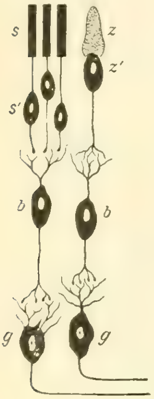

FIG. 267.—RETINAL CELLS. *s′*, *z′*. Visual cells with their peripheral terminations. *s*. Rods. *z*. Cones. *b*. Bipolar cells. *g*. Ganglion cells from which arise the axons of the optic nerve.

The *visual cells* present peripherally modified dendrites, known as the rods and cones; centrally they give off an axon which after a short course terminates in an end-tuft. The *bipolar cells* also possess dendrites and an axon; the former interlace with the end-tufts of the visual cell axon, the latter with the dendrites of the ganglion cell. The retina may be regarded therefore as the peripheral end-organ in which the optic nerve originates. From their origin the axons turn backward, at the same time converging to form a distinct bundle which passes through the chorioid coat and sclera. After emerging from the eyeball the nerve-bundle (the optic nerve) passes backward as far as the sella turcica, traversing in its course the orbit cavity and the optic foramen. At the sella turcica there is a union and partial decussation in man and other mammals of the two nerves, forming the *optic chiasm*.*

Decussation of the Optic Nerves.—The extent to which the fibers from each eye decussate at the chiasm is a subject of dispute but the results of various methods of research would seem to indicate, that the fibers from the nasal third of the retina of the left eye cross in the chiasm, to unite with the fibers from the temporal two-thirds of the retina of the right eye. In a similar manner the fibers from the nasal third of the retina of the right eye cross in the chiasm, and unite with the fibers from the temporal two-thirds of the retina of the left eye (Fig. 268). Posterior to the chiasm the crossed and uncrossed fibers form the so-called optic tracts, which after winding around the crura cerebri enter the optic basal ganglia. Transection of the optic nerve shows that it is composed of an enormous number of non-medullated nerve-fibers, estimated by Salzer at from 450,000 to 800,000, enclosed in a sheath of the dura mater.

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* Though the foregoing is the usual method of stating the origin and course of the optic nerve, nevertheless morphologically the true optic nerve lies wholly within the retina and is composed of the visual cells there found. The remainder of the visual system from and including the ganglion cells of the retina to the optic basal ganglia, is the optic tract, there being no anatomic or physiologic distinction between the optic nerve so called and the optic tract. Both are outgrowths from the brain and hence possess properties which differentiate them from other cranial nerves.

The visual fibers comprising the optic nerve may be physiologicly divided into two classes, (a) those coming from the peripheral portion of the retina, and (b) those coming from that central area known as the macula lutea. The retinal fibers are by far the more abundant, and make up the major portion of the nerve; the macular fibers are less abundant. An examination of a cross-section of the optic nerve shows the presence of a wedge-shaped tract occupying the center of the nerve and which is regarded as composed of the macular fibers At the chiasm this bundle of fibers undergoes a partial decussation similar to that of the fibers coming from the more peripheral portions of the retina. In the left optic tract, therefore, fibers from at least four different regions are to be found: viz., the two-thirds of the temporal side of the left retina, the temporal half of the left macula, the nasal third of the right retina, and the nasal half of the right macula. Corresponding fibers are to be found in the right optic tract. As the optic tract passes around the crus cerebri it divides into a lateral or outer, and a mesial or inner bundle, which then terminate in **the optic basal ganglia.** The fibers of the lateral bundle are traceable into the lateral or external geniculate body (the pre-geniculum), the pulvinar of the optic thalamus, and the anterior quadrigeminal body (the pre-geminum). These are in all probability the true visual fibers. The fibers of the mesial bundle are traceable into the internal geniculate body (the post-geniculum) and the posterior quadrigeminal body (the post-geminum).

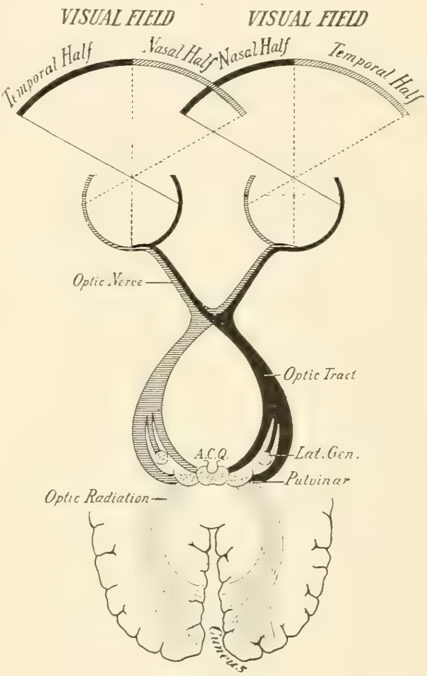

Fig. 268.—Diagram Illustrating Left Homonymous Lateral Hemianopsia from a Lesion of the Right Optic Tract or the Right Cuneus. The Shaded Lines in the Visual Fields Indicate the Darkened Area.

Cortical Connections.—After entering the basal ganglia the visual fibers terminate in end-tufts which arborize around nerve-cells. From these cells new axons arise which ascend through the posterior part of the internal capsule, at the same time curving backward to form the optic radiation of Gratiolet, and terminate finally around nerve-cells in the gray matter of the cuneus and in the gray matter bordering the calcarine fissure, both situated on the mesal aspect of the occipital lobe.

Centrifugal Fibers of the Optic Nerve.—All the fibers previously alluded to have been afferent or centripetal in direction; but the optic nerve also contains efferent or centrifugal fibers which come from nerve-cells in the basal ganglia and ramify around special cells, the amacrine cells, in the retina. Their function is unknown. It has been suggested that they regulate the vascular supply to the retina. Centrifugally coursing fibers also connect the visual areas of the cortex with the basal ganglia.

Function.—The function of the visual apparatus in its entirety is the transmission of nerve impulses from the retina to the cerebral cortex where they evoke the sensations of light and its different qualities—colors. The specific physiologic stimulus to the retinal visual cells is the impact of the undulations of the ether. In general it may be said that, at least for the same color, the intensity of the objective undulation or vibration, determines the intensity of the sensation.

Pupillary Fibers.—The optic nerve also contains nerve-fibers somewhat larger in caliber than the usual visual fibers, which are supposed to form the afferent path for those nerve impulses which excite reflexly a contraction of the *sphincter pupillæ* muscle, thus varying the size of the pupil. These fibers, termed pupillary fibers, come from all portions of the retina but most abundantly from the posterior pole in and around the macula. The existence of these fibers is confirmed by pathologic findings. In a manner similar to that of the visual fibers they, too, undergo a decussation in the optic chiasm, so that in the optic tract there are pupillary fibers which come from the temporal side of the eye of the corresponding side, and fibers which come from the nasal side of the eye of the opposite side (Fig. 272). The central termination of these fibers is not positively known.

Hemiopia and Hemianopsia.—Division of the optic nerve between the eyeball and the optic chiasm is followed by complete blindness in the eye of the corresponding side. Owing to the partial decussation of the fibers in the chiasm, division of an *optic tract* is followed by a loss of sight in the *outer two-thirds* of the eye of the same side and in the inner third of the eye of the opposite side. To this loss of visual power in the retina the term *hemiopia* is given. In consequence of this loss of visual power in the retina there is a corresponding obscuration or total obliteration of nearly one-half of the visual field, to which the term *hemianopsia* is given. If, for example, the *right optic tract* is divided there will be hemiopia in the outer two-thirds of the right eye and the inner third of the left eye, with *left lateral hemianopsia*, and as the portions of the retina which are affected are associated in vision the loss of the visual fields is spoken of as homonymous hemianopsia (Fig. 268). A destructive lesion of the cerebral visual area, the cuneus and the adjacent gray matter on the right side, is also followed by left lateral hemianopsia.*

The existence of an homonymous hemianopsia becomes evident when the individual is directed to focus the vision on an object placed directly in front and with its center in the median plane of the body, when if the lesion be on the right side, the left half of the object will be invisible. The reason for this will be apparent on reference to Fig. 269. All the light rays emanating from the left half of the object fall on the retina on the side of the injury, and hence there will be no sensation. If, however, the object be moved to the right without change in the position of the head, the entire object will be visible, as all the rays fall on the normal side. If, on the contrary, the object be moved to the left, it will be invisible for the opposite reason.

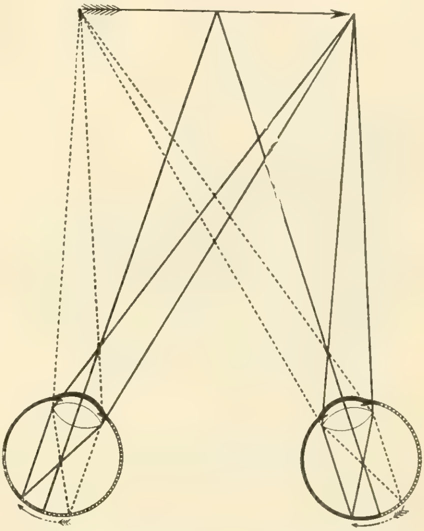

FIG. 269.—DIAGRAM TO SHOW THE EXISTENCE OF HEMIANOPSIA. The lesion is supposed to be in the right optic tract.

Hemianopsia may be the result of either destruction of the optic tract or of the cortical visual area. The seat of lesion in any given case is indicated by a peculiarity of the iris reflex pointed out by Wernicke, which will be referred to in connection with the consideration of the oculo-motor nerve.

THIRD PAIR. THE OCULO-MOTOR.

The third cranial nerve, the oculo-motor, consists of some 15,000 peripherally coursing nerve-fibers which serve to bring the nerve-cells from which they arise into relation with a large portion of the general musculature of the eye.

Origin.—The axons composing the third nerve arise from a series of seven or eight groups of nerve-cells, located in the gray matter beneath the floor of the aqueduct of Sylvius. From each of these groups or nuclei, bundles of axons emerge, which after a short course unite to form the common trunk. The large majority of the fibers in the nerve come directly from the nuclei of the same side; the remainder come from a group of cells on the opposite side of the median line. There is thus a partial decussation of its fibers (Fig. 270).

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* It should be borne in mind that in both instances the retina itself is unaffected. The impact of light generates, as usual, nerve impulses which proceed as far backward as the point of division or destruction. In consequence those portions of the cerebral cortex stimulation of which evokes the sensation of light remain unaffected and the individual does not become aware through sensation, of the presence of a luminous body in the left side of the visual field.

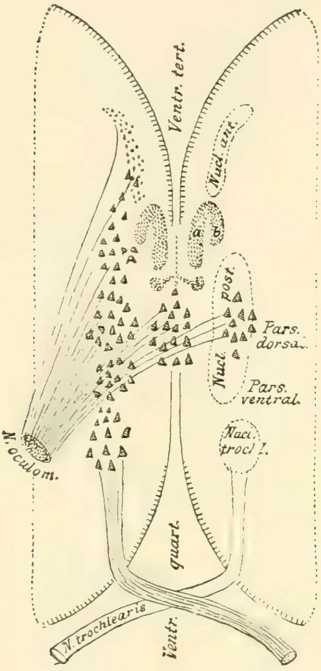

FIG. 270.—DIAGRAMMATIC VIEW OF THE SITUATION AND RELATION OF THE NUCLEI OF ORIGIN OF THE OCULO-MOTOR AND PATHETICUS (TROCHLEARIS) NERVES. The oculo-motor nuclei consist of an anterior nucleus, the Edinger-Westphal nucleus (*a* and *b*), and a posterior nucleus; the posterior nucleus has a dorsal, a ventral, and a mesial portion; the decussation of fibers from the dorsal portion of the posterior nucleus is also shown. The decussation of the fibers of the fourth nerve is also represented. —(*Edinger.*)

The different groups of cells, the nuclei of origin, are arranged in a serial manner. The anatomic arrangement of these nuclei would indicate that each nucleus is related to an individual member of the eye-group of muscles. Clinical observation and the investigation of the results of pathologic processes have not only shown that this is the case, but have succeeded in locating the position of the nucleus for any given muscle. Though there is some difference of opinion in regard to the exact location of one or two of the nuclei, the tabulation subjoined is approximately correct.

Enumerating them from before backward, the nuclei occur in the following order:

1. The sphincter pupillæ.
2. The tensor chorioideæ (the accommodation nucleus).
3. The convergence nucleus, a common nucleus for the *conjoint* action of the two internal recti muscles.
4. The superior rectus.
5. The inferior rectus.
6. The levator palpebræ.
7. The inferior oblique.

Cortical Connections.—The oculo-motor nuclei are in histologic and physiologic relation with the motor area of the cerebrum. Nerve-cells in the cortex give off axons which, entering the pyramidal tract, descend through the internal capsule, and the crus cerebri, from which they cross to the opposite side. The end-tufts arborize around the nuclei of the oculo-motor nerve with the exception of the nucleus for the iris sphincter.

Distribution.—After their origin the axons converge to form a common trunk, which emerges from the base of the encephalon, on the inner side of the crus cerebri, in front of the pons Varolii. The nerve then passes forward through the sphenoid fissure into the orbit cavity, where it divides into a *superior* and an *inferior* branch. The former is distributed to the *superior rectus* and the *levator palpebræ* muscles; the latter is distributed to the *internal* and *inferior recti* and *inferior oblique* muscles (Fig. 271).

From the inferior branch a short bundle of fibers passes to the *ciliary* or *ophthalmic* ganglion, where they terminate, arborizing around the ganglion cells. These fibers are smaller in size than those constituting the bulk of the nerve and belong to the system known as the autonomic. These cells give origin to new axons, *the ciliary nerves*, which enter the eyeball, pass forward between the sclera and chorioid coat, and terminate in the *ciliary muscle* and the *sphincter* of the pupil. The ciliary nerves are not portions of the third nerve proper, but peripheral sympathetic neurons. As the ciliary ganglion receives filaments from the cavernous plexus of the sympathetic and filaments which become a part of the trigeminal nerve, it is probable that the ciliary nerves contain not only motor, but vaso-motor and sensor fibers as well.

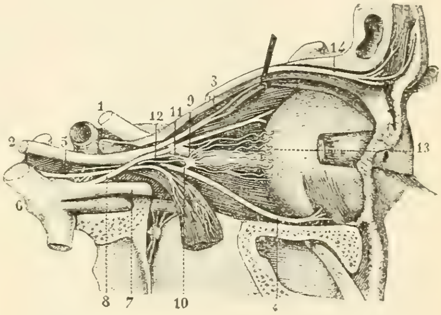

FIG. 271.—INTRA-ORBITAL PORTION OF THE THIRD NERVE. 1. Optic nerve. 2. *Third nerve.* 3. *Superior branch.* 4. *Inferior branch.* 5. Abducens. 6. Trifacial. 7. Ophthalmic branch divided. 8. Nasal branch. 9. *Ciliary ganglion.* 10. *Motor branch* to this ganglion from the inferior branch of the third nerve. 11. Sensory fibers. 12. Sympathetic fibers. 13. *Ciliary nerves.*—(*Sappey.*)

Properties.—*Stimulation* of the nerve near its exit from the encephalon is followed by contraction of the muscles to which it is distributed with the following results, viz.:

1. Diminution in the size of the pupil.
2. Accommodation of the eye for near vision.
3. Elevation of the upper eyelid.
4. Internal deviation and rotation upward and inward of the anterior pole of the eye, combined with a small amount of torsion toward the mesial line, due to preponderating action of the internal rectus and inferior oblique muscles.

Division of the nerve either experimentally or as a result of compression from a pathologic cause is followed by a relaxation of the muscles, with the following effects, viz.:

1. Dilatation of the pupil, the iris responding neither to light nor to efforts of accommodation.

2. Loss of the accommodative power.
3. Falling of the upper eyelid (ptosis).
4. External deviation and rotation downward and outward of the anterior pole of the eyeball combined with a small amount of torsion toward the mesial line due to the unopposed action of external rectus and the superior oblique muscles.
5. Double vision or diplopia. The image of the eye of the paralyzed side is projected to the opposite side of the true image and to the upper part of the visual field. Owing to the slight mesial torsion the false image is inclined away from the true image.
6. Immobility and slight protrusion of the eyeball.

Function.—The function of the third nerve is to transmit nerve impulses from the nuclei of origin to all the muscles of the eye except the external rectus and superior oblique and excite them to activity. The majority of the ocular movements, the power of accommodation, the variations in the size of the pupil in accordance with variations in the intensity of the light, the power of convergence of the visual axes, are all excited by the transmission of nerve impulses by the constituent fibers of the nerve from their related nuclei. This is made evident by the effects which follow stimulation and division of the nerve or lesions of the nuclei themselves.

The central nuclei can be excited to activity (1) by nerve impulses descending the motor tract, from the cerebral cortex, (2) by nerve impulses coming through various afferent nerves. This holds true more especially for the sphincter pupillæ nucleus.

The Iris Reflex or the Pupillary Reflex.—These are terms applied to the variations in the size of the pupil that follow variations in the intensity of the light. In the absence of light the pupil widely dilates, due largely to the relaxation of the *sphincter pupillæ* muscle and partly to a contraction of the radiating fibers of the iris which collectively constitute the *dilatator pupillæ* muscle. With the entrance of light into the eye, the pupil diminishes in size, in consequence of the contraction of the *sphincter pupillæ* caused by a stimulation of the peripheral ends of the pupillary fibers of the retina, the degree of contraction depending within limits on the intensity of the light.

The action of the sphincter pupillæ muscle is therefore a reflex action and involves the usual mechanism, viz.: A receptive surface, the retina; afferent nerves, the pupillary fibers in the optic nerve; an emissive center, the sphincter nucleus of the motor oculi center; efferent nerves, including fibers in the trunk of the motor oculi and in the ciliary nerves; and a responsive organ, the muscle. (See Fig. 272.) That this is the mechanism involved in this reflex, is shown by the fact that when any portion of it is destroyed, the reflex contractions of the sphincter are impaired or abolished.

As stated in a preceding paragraph the central termination of the afferent pupillary fibers concerned in this reflex is not positively known. No one has as yet succeeded in tracing these fibers directly to the sphincter nucleus. Experimental and pathologic data apparently disprove the probability of their terminating in the anterior corpora quadrigemina. It has been shown, however, that as the optic tract approaches its termination the visual and the pupillary fibers separate and it has been assumed that the latter come into anatomic relation with some intercalated system which in turn is connected with the sphincter nucleus. As to the situation, origin and course of this system nothing positively is known. There is some evidence for the view that these two systems are associated by commissural fibers.

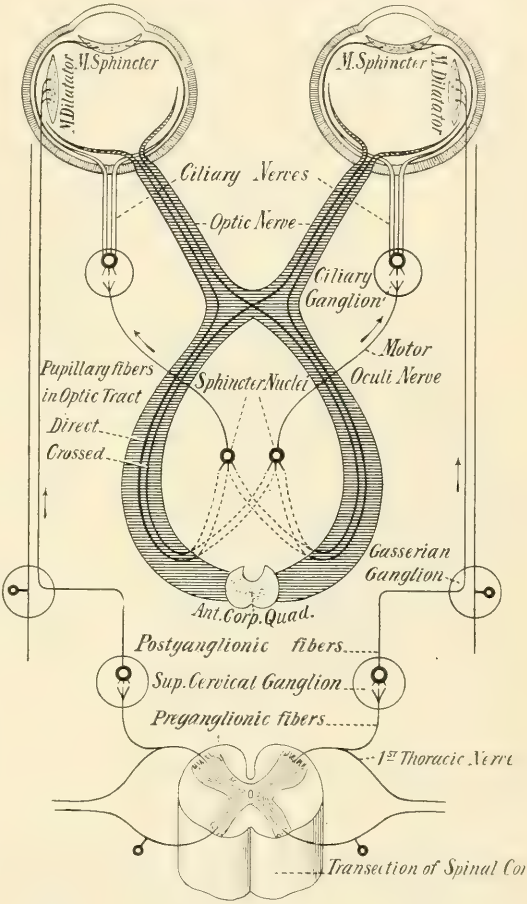
M.Dilatator
M.Sphincter
M.Sphincter
M.Dilatator
Ciliary Nerves
Optic Nerve
Ciliary Ganglion
Motor Oculi Nerve
Pupillary fibers in Optic Tract
Sphincter Nuclei
Direct
Crossed
Gasserian Ganglion
Ant.Corp.Quad.
Postganglionic fibers
Sup.Cervical Ganglion
Preganglionic fibers
1st Thoracic Nerve
Transection of Spinal Cord

FIG. 272.—DIAGRAM DESIGNED TO SHOW THE MECHANISM OF THE IRIS REFLEX. The central termination of the pupillary fibers is hypothetical.

The contraction of the sphincter and a diminution in the size of the pupil, may be direct, as when the light which enters one eye causes a reflex contraction of the sphincter of one and the same side; or it may be indirect or consensual, as when the light, which enters one eye only, causes a contraction of the sphincter not only in the eye of the same, but in the eye of the opposite side also. It is, however, highly probable that all reflex contractions of the sphincter muscles are consensual, that is, bilateral reflex actions because of the decussation of the pupillary fibers at the chiasm. Contraction of both pupils also occurs as an associated movement in the convergence of the eyes during accommodation.

The dilatation of the pupil is, however, not due exclusively to the relaxation of the sphincter pupillæ muscle, but partly to the contraction of the dilatator pupillæ muscle, which is kept normally in a state of tonic contraction by impulses emanating from a nerve-center in the medulla oblongata.

The axons which arise in this center pass down the cord, emerge through the first thoracic nerve, and then ascend to the superior cervical ganglion (see Fig. 272), in which their terminal branches arborize around its nerve-cells. From these cells new axons of the sympathetic system arise which pass successively to the ophthalmic division of the fifth nerve, the nasal nerve, the long ciliary nerve and he iris.

Experimental research renders it highly probable that the dilatator center is in a state of continuous activity and the dilatator muscle in a state of tonic contraction. Whatever the normal stimulus may be, the center is increased in activity by dyspneic blood, by severe muscle exercise, by emotional excitement, and by stimulation of various sensor nerves. That the efferent pathway just alluded to transmits the impulses to the iris is shown by the fact that division in any part of the course is followed by narrowing, stimulation by active dilatation of the pupil.

The variations in the size of the pupil, though largely a reflex act under the control of the oculo-motor nerve, are nevertheless partly due to the active coöperation of the dilatator nerves and their related muscle. The size of the pupil necessary from moment to moment for the admission of just that amount of light essential to the formation and perception of a distinct image is the result of two nicely adjusted and delicately balanced forces.

Wernicke's Hemianopic Pupillary Reaction.—It was stated on page 585 that a modification of the pupillary reaction is observed in some cases of hemianopsia, which indicates approximately the seat of the lesion. This reaction, or inaction as it is sometimes called, is present when the lesion is along the course of the optic tract between the chiasma and the anterior quadrigeminal body. In a case of left lateral hemianopsia, the lesion being in the right optic tract, the method of testing for the reaction is as follows: The eye of the left side is first carefully shielded from the light. A fine ray of light is then projected into the right eye in such a manner that it falls entirely on the non-sensitive (the temporal) side of the retina. There will be an absence of the usual pupillary response, or rather the pupil remains inactive; but if the light is gradually directed towards the sensitive (the nasal) side of the retina, there will come a moment, as the central line is crossed and the light falls on the sensitive side, when the usual pupillary response manifests itself, viz.: a contraction of the sphincter pupillæ and a diminution in the size of the pupil. The explanation of these facts will become apparent from an examination of Fig. 272 in which the course of the pupillary fibers is shown and especially if it be accepted that these fibers at their central terminations decussate or are in relation either directly or indirectly with the **sphincter centers.**

The eye of the right side is then in turn shielded from the light and the same method of examination is carried out. In this case, however, the light is projected first on the nasal, which is the non-sensitive side of the retina; there will again be no response in the pupil. But if the light is gradually directed towards the sensitive (the temporal) side, there will come a moment, as the central line is crossed and the light falls on the sensitive portion of the retina, when the usual pupillary response manifests itself. The course of the pupillary fibers in this instance will also become apparent from an examination of Fig. 272. It is evident, however, that in either case a bilateral pupillary reaction will follow stimulation of the sensitive side of either eye because of the central decussation of the pupillary fibers.

FOURTH PAIR. THE PATHETICUS.

The fourth cranial nerve, the patheticus, consists of peripherally coursing axons which serve to bring the cells from which they arise into relation with the superior oblique muscle.

Origin.—The axons of this nerve arise from a group of cells located beneath the aqueduct of Sylvius just posterior to the last nucleus of the third nerve. After emerging from the nucleus the nerve-fibers pass downward for a short distance, then curve dorsally around the aqueduct of Sylvius, and enter the valve of Vieussens, where they completely decussate with the nerve-fibers of the opposite side.

Cortical Connections.—The nucleus of the pathetic nerve is in histologic and physiologic connection with the motor area of the cerebral cortex. Nerve-cells in this region give off axons which enter the pyramidal tract and descend through the internal capsule and the crus cerebri, after which they cross to the opposite side. Their end-tufts arborize around the cells of the nuclei already described.

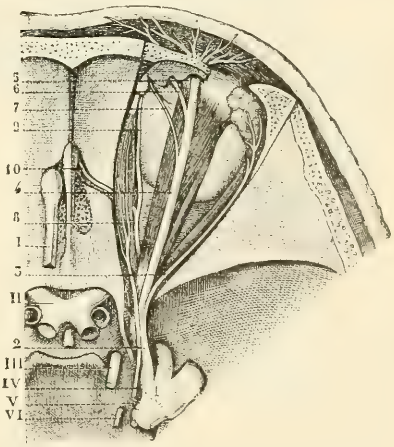

FIG. 273.—DISTRIBUTION OF THE PATHETICUS. I. Olfactory nerve. II. Optic nerves. III. Motor oculi communis. IV. Patheticus, by the side of V the ophthalmic branch of the fifth, and passing to the superior oblique muscle. VI. Motor oculi externus. 1. Ganglion of Gasser. 2, 3, 4, 5, 6, 7, 8, 9, 10. Ophthalmic division of the fifth nerve, with its branches.—(*Hirschfeld.*)

Distribution.—After its decussation the nerve-trunk emerges just below the posterior quadrigeminal body, crosses the superior cerebellar peduncle, and winds around the crus cerebri to the anterior border of the pons Varolii. It then enters the orbit cavity through the sphenoid fissure and finally terminates in the *superior oblique* muscle. In its course the nerve receives filaments from the cavernous plexus of the sympathetic and the ophthalmic division of the trigeminal (Fig. 273).

Properties.—*Stimulation* of the nerve-trunk is followed by spasmodic contraction of the superior oblique muscle, the anterior pole of the eyeball being turned downward and outward, combined with slight torsion away from the middle line.

Division of the nerve is followed by a relaxation or paralysis of the muscle. In consequence of the now unopposed action of the inferior oblique muscle, the anterior pole of the eyeball is turned upward and *inward* with slight torsion toward the middle line. The diplopia consequent upon this paralysis is homonymous, the images appearing one above the other. The image of the paralyzed eye is below that of the normal eye and its upper end inclined toward that of the normal eye.

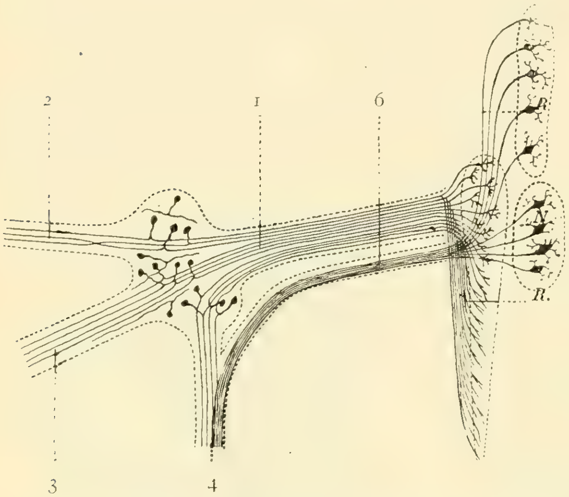

FIG. 274.—SCHEME OF ORIGIN AND CONSTITUTION OF THE TRIGEMINAL NERVE. 1. Centrally coursing fibers. 2, 3, 4. Peripherally coursing fibers of the cells of the ganglion of Gasser. *R*, *N*. Nuclei of origin of the efferent fibers. 6. Motor root. Central terminations of the large root.

Function.—The function of this nerve is to transmit nerve impulses to the superior oblique muscle and to excite it to contraction.

FIFTH PAIR. THE TRIGEMINAL.

The fifth cranial nerve, the trigeminal, consists of both afferent and efferent axons which for the most part are separate and distinct. The afferent axons constitute by far the major portion, the efferent fibers the minor portion, of the nerve.

Origin of the Afferent Axons.—The afferent axons have their origin in the monaxonic cells in the ganglion of Gasser, which rests on the apex of the petrous portion of the temporal bone. The cells of this ganglion give origin to a short process which soon divides into two branches, one of which passes centrally, the other peripherally (Fig. 274). The centrally directed branches collectively form the so-called large or sensor root; the peripherally directed branches collectively constitute the three main divisions of the nerve: viz., the ophthalmic, the superior maxillary, and the inferior maxillary. Branches of the carotid plexus of the sympathetic enter the nerve in the neighborhood of the ganglion of Gasser and accompany some of its branches to their terminations.

Distribution.—1. *The Central Branches.*—The axons of the large root pass backward into the pons Varolii on its lateral aspect. After entering the pons each axon divides into two branches, one of which passes upward a short distance, the other passes downward, descending as far as the second cervical segment. Both branches give off a number of collaterals, some of which terminate in fine end-tufts around nerve-cells in the substantia gelatinosa.

2. *The Peripheral Branches.*—The peripheral axons emerge from the peripheral end of the ganglion of Gasser in three distinct and separate branches, each of which is distributed to a different region of the face and head.

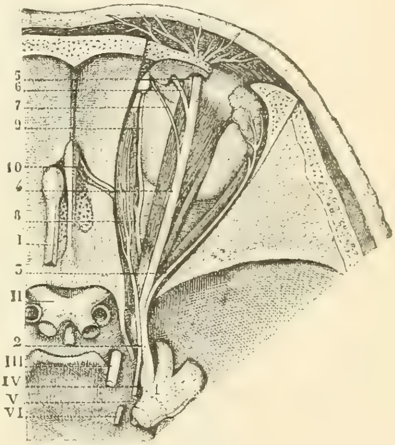

FIG. 275.—OPHTHALMIC BRANCH OF THE FIFTH. 1. Ganglion of Gasser. 2. Ophthalmic division of the fifth. 3. Lachrymal branch. 4. Frontal branch. 5. External frontal. 6. Internal frontal. 7. Supratrochlear. 8. Nasal branch. 9. External nasal. 10. Internal nasal.—(*Hirschfeld.*)

1. The *ophthalmic branch* passes forward and subdivides into three large branches, the frontal, the lachrymal, and the nasal. The ultimate termination of the branches of these nerves is as follows: viz., the conjunctiva and skin of the upper eyelid, the cornea, the skin of the forehead and the nose, the lachrymal gland and caruncle, and the mucous membrane of the nose (Fig. 275).
2. The *superior maxillary branch* passes forward through the foramen rotundum, crosses the spheno-maxillary fossa, enters the infra-orbital canal, and emerges at the infra-orbital foramen. In its course it gives off a number of branches which are distributed as follows: viz., to the integument and conjunctiva of the lower lid, the nose, cheek, and upper lip, the palate, the teeth of the upper jaw, and the alveolar processes (Fig. 276).
3. The *inferior maxillary branch* passes through the foramen ovale, after which it subdivides into three branches—the auriculo-temporal, the lingual, and the inferior dental. The ultimate branches are distributed as follows: viz., the external auditory meatus, the side of the head, the mucous membrane of the mouth, the anterior portion of the tongue, the arches of the palate, the teeth and

alveolar process of the lower jaw and the integument of the lower part of the face (Fig. 277).

The afferent axons thus serve to bring into relation the skin, mucous membranes of the head and face, and other sentient structures, with certain sensor end-nuclei in the pons, medulla oblongata, and adjoining structures.

Cortical Connections.—The afferent portion of the trigeminal nerve is brought into physiologic relation with the sensor portion of the cerebral cortex by means of nerve-fibers, which have their origin in the cells around which the terminal branches of the centrally coursing fibers arborize. The cells situated in the substantia gelatinosa give off axons, which after a short course cross the median line, enter the fillet and then ascend in the general sensor tract to the cortex where they in turn arborize around sensor nerve-cells.

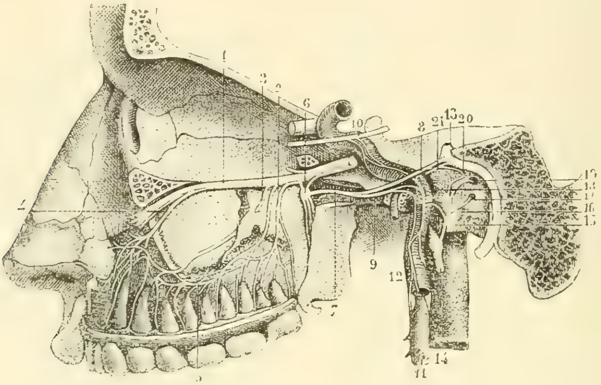

FIG. 276.—1. Superior maxillary nerve. 2, 3, 4, 5. Dental nerves. 6. Sphenopalatine ganglion. 7. Vidian nerve. 8. Large superficial petrosal. 9. Carotid branch of large petrosal. 10. Oculo-motor. 11. Superior cervical ganglion. 12. Carotid branches of this ganglion. 13. Facial. 14. Glosso-pharyngeal. 15. Jacobson's nerve, and 16, 17, 18, 19, branches to the sympathetic, fenestra rotunda, Eustachian tube. 20. Deep external petrosal. 21. Deep internal petrosal.—(*Hirschfeld.*)

Properties.—Irritative pathlogic lesions, *e. g.*, pressure by tumors, aneurysms, neuritis, degenerative changes in the ganglion cells, or lesions which in any way gradually impair the physical or chemic integrity of the nerve-fibers, give rise to a variety of painful sensations referable to the seat of the lesion or to one or more regions in the peripheral distribution of the nerve. Many of the various forms of trigeminal neuralgia are caused by lesions of this character. Exposure of the dental nerves from caries of the teeth, the presence of minute foreign bodies in the conjunctiva, operative procedures in the nasal chambers, all testify to the extreme sensibility of the nerve. Division of the *large root* within the cranium is followed at once by complete abolition of all sensibility in the head and face to which its branches are distributed. The skin and mucous membranes, the eye, nose, or teeth may be experimentally injured without any evidences of pain on the part of the animal. Various reflexes, *e. g.*, those of mastication, insalivation, deglutition, the afferent paths of which are formed in part by the fifth nerve, are often seriously impaired. At the same time the lachrymal secretion diminishes and the pupil contracts. The same results are observed in human beings in whom the nerve has been divided for relief from neuralgia. Anesthesia or a loss of sensibility may also be caused by pathologic lesions of the nerve-trunks or of the sensor end-nuclei.

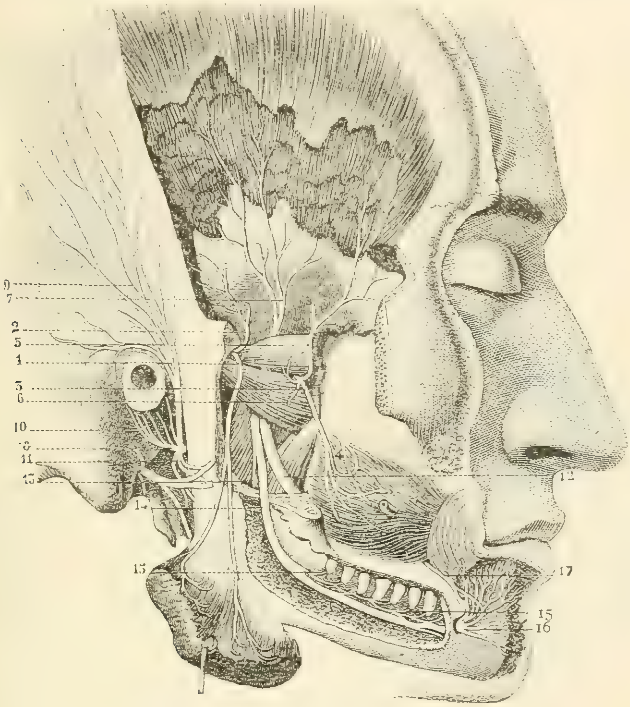

FIG. 277.—INFERIOR MAXILLARY BRANCH OF THE TRIGEMINAL NERVE. 1. Branch to the masseter muscle. 2. Filament of this branch to the temporal muscle. 3. Buccal branch. 4. Branches anastomosing with the facial nerve. 5. Filament from the buccal branch to the temporal muscle. 6. Branches to the external pterygoid muscle. 7. Middle deep temporal branch. 8. Auriculo-temporal nerve. 9. Temporal branches. 10. Auricular branches. 11. Anastomosis with the facial nerve. 12. Lingual branch. 13. Branch of the small root to the mylo-hyoid muscle. 14. Inferior dental nerve, with its branches (15, 15). 16. Mental branch. 17. Anastomosis of this branch with the facial nerve.—(*Hirschfeld.*)

Division of the large root at or near the ganglion of Gasser has not infrequently been followed by an alteration in the nutrition of the eye and nose. In the course of twenty-four hours the eye becomes vascular and inflamed; the cornea becomes opaque; ulceration sets in which may lead to complete destruction of the eyeball. The mucous membrane of the nose becomes swollen, vascular, and liable to hemorrhage on the slightest irritation. The degenerative changes may lead to a complete loss of the sense of smell. These results were formerly attributed to a loss of *trophic* influence which it was believed the nerve exercised over these structures. Modern experimentation and various surgical procedures have demonstrated that the nutritive disorders are septic in origin, made possible by the anesthetic condition and by the changed vascular supply from division of the vasomotor fibers which join the nerve at or near the ganglion.

Origin of the Efferent Axons.—The efferent axons arise for the most part from nerve-cells located in the gray matter beneath the upper half of the floor of the fourth ventricle. A group of cells known as the superior or accessory nucleus, situated posterior to the corpora quadrigemina, give origin to axons which descend and join the axons from the chief motor nucleus (Fig. 274).

Distribution.—From their origin the fibers pass forward through the pons and emerge on its lateral aspect, forming the so-called small root of the fifth nerve. This then passes forward beneath the ganglion of Gasser, leaves the cavity of the skull through the foramen ovale, and joins the inferior maxillary division already described. Its axons are ultimately distributed to the muscles of mastication: viz., the masseter, the temporal, the external and internal pterygoids, the mylohyoid, and the anterior portion of the digastric. A few axons are also distributed to the tensor tympani and tensor palati muscles. The efferent or peripherally coursing axons thus serve to bring the nerve-cells from which they arise into relation with the muscles of mastication.

Cortical Connections.—The nuclei of origin of the small root are in histologic and physiologic relation with the lower third of the motor area of the cerebral cortex. Nerve-cells in this region give off axons which enter the pyramidal tract, descend through the internal capsule and the crus cerebri, after which they cross to the opposite side. Their end-tufts arborize around the cells of nuclei in the medulla oblongata.

Properties.—*Stimulation* of the small root gives rise to convulsive movements of the muscles of mastication. *Division* of the nerve is followed by a paralysis of these muscles. Contraction or paralysis of the tensor tympani and tensor palati muscles would also be observed under the same conditions.

Functions.—The function of the afferent fibers of the fifth nerve is the transmission of nerve impulses from its peripheral distribution to (a) the medulla oblongata; (b) through its afferent cortical tracts to the cerebral cortex where they evoke sensations. The nerve therefore endows all the parts to which it is distributed with sensibility.

The function of the efferent fibers is the transmission of nerve impulses from the cells from which they take their origin, to the muscles of mastication which are excited to activity by them. The afferent nerves are in relation centrally with the nuclei of origin of the efferent nerves, hence the latter can be excited not only voluntarily but reflexly as in the usual acts of mastication. The afferent fibers from the mouth doubtless assist in the reflex secretion of saliva.

Peripheral stimulation of different areas in the distribution of the afferent fibers, *e. g.*, conjunctiva, nasal and oral mucous membranes, teeth, etc., causes a variety of reflex activities in the muscles associated with the eyes, face, the respiratory and cardiac mechanisms, which indicate that the afferent fibers are centrally in relation with a number of motor nerve centers.

SIXTH PAIR. THE ABDUCENS.

The sixth cranial nerve, the abducens, consists of peripherally coursing axons which serve to bring the nerve-cells from which they arise into relation with the *external rectus* muscle.

Origin.—The axons arise from a group of cells located in the gray matter beneath the upper half of the floor of the fourth ventricle. It is quite probable that a few fibers in each nerve-trunk come from the nucleus on the opposite side of the middle line.

Distribution.—The nerve-fibers pass forward from their origin through the gray and white matter and emerge through the groove between the medulla oblongata and the pons Varolii just external to the anterior pyramid. The nerve then passes through the sphenoid fissure into the orbit cavity, where it is distributed to the *external rectus* muscle (Fig. 278). In its course the nerve receives filaments from the carotid plexus of the sympathetic.

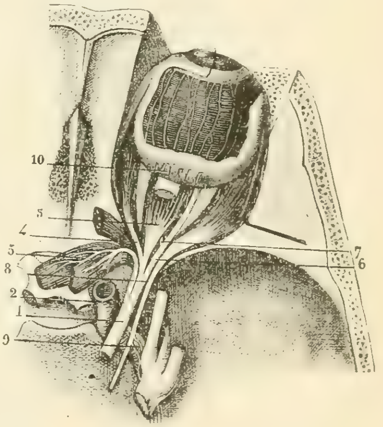

FIG. 278.—DISTRIBUTION OF THE MOTOR OCULI EXTERNUS OR ABDUCENS. 1. Trunk of the motor oculi communis, with its branches (2, 3, 4, 5, 6, 7). 8. Motor oculi externus, passing to the external rectus muscle. 9. Filaments of the motor oculi externus anastomosing with the sympathetic. 10. Ciliary nerves. —(*Hirschfeld.*)

Cortical Connections.—The nucleus of the sixth nerve is in histologic and physiologic connection with the motor area of the cerebral cortex. From nerve-cells in this region axons are given off which enter the pyramidal tract, descend through the internal capsule and crus cerebri, after which they cross to the opposite side, where their end-tufts arborize around the cells of the nucleus already described.

Properties.—*Stimulation* of the nerve is followed by spasmodic contraction of the external rectus muscle and external deviation of the eyeball. *Division* of the nerve is followed by paralysis or relaxation of the muscle. As a result of the unopposed action of the internal rectus the anterior pole of the eyeball is turned toward the middle line (internal strabismus). In consequence of this deviation there is homonymous diplopia. The images are on the same level and parallel. The image of the paralyzed eye lies external to that of the normal eye.

Function.—The function of this nerve is to transmit nerve impulses to the external rectus muscle and excite it to contraction.

SEVENTH PAIR. THE FACIAL.

The seventh cranial nerve, the facial, consists of peripherally coursing nerve-fibers, which serve to bring the nerve-cells from which they arise into relation with most of the superficial muscles of the head and face.

The muscles supplied by this nerve, as stated by the general anatomists, are as follows: The occipito-frontalis, corrugator supercilii, orbicularis palpebrarum, levator labii superioris, alæque nasi, zygomatici, the pyramidalis nasi, the compressor nasi, the depressor alæ nasi, levator anguli oris, buccinator, orbicularis oris, depressor anguli oris, depressor labii inferioris, the levator menti, the posterior belly of the digastric, the stylo-hyoid, and the platysma myoides.

Origin.—The nerve-fibers or axons composing the seventh nerve arise for the most part from a nucleus of large multipolar nerve-cells situated about five millimeters beneath the upper half of the floor of the fourth ventricle toward the middle line.

From this nucleus, which is about four millimeters long, axons emerge which at first pass inward and backward as far as the ependyma of the ventricle; they then turn on themselves, forming an arch that encloses the nucleus of the sixth nerve; they then course downward and outward, emerging from the pons at its lower border between the olivary and restiform bodies. As the axons approach the floor of the ventricle collateral branches are given off which, crossing the median line, arborize around the nerve-cells of the opposite facial nucleus.

Clinic observations and histologic investigations, however, render it probable that the fibers distributed to the occipito-frontalis, the corrugator supercilii, and the upper half of the orbicularis palpebrarum, are derived from the oculo-motor nucleus, and, descending the posterior longitudinal bundle, enter the trunk of the facial as it turns to pass forward through the pons. It is also probable, for similar reasons, that the fibers distributed to the orbicularis oris are derived from the hypoglossal nucleus.

Cortical Connections.—The nucleus of the facial nerve is in histologic and physiologic connection with the facial region of the general motor area of the cerebral cortex. From the cells of this region axons descend through the pyramidal tract, the internal capsule, and the crus cerebri, beyond which they cross to the opposite side and arborize around the cells of the nucleus already described.

Distribution.—From its superficial origin the trunk of the nerve passes into the internal auditory meatus beside the auditory nerve. After passing forward and outward for a short distance through the bone above and between the cochlea and vestibule, the nerve makes a sharp bend, forming the genu facialis, turns backward and enters the aqueduct of Fallopius, the general course of which it follows as far as the stylo-mastoid foramen. After emerging from this foramen the nerve passes downward and forward as far as the parotid gland, within which it terminates by dividing into two main branches, the

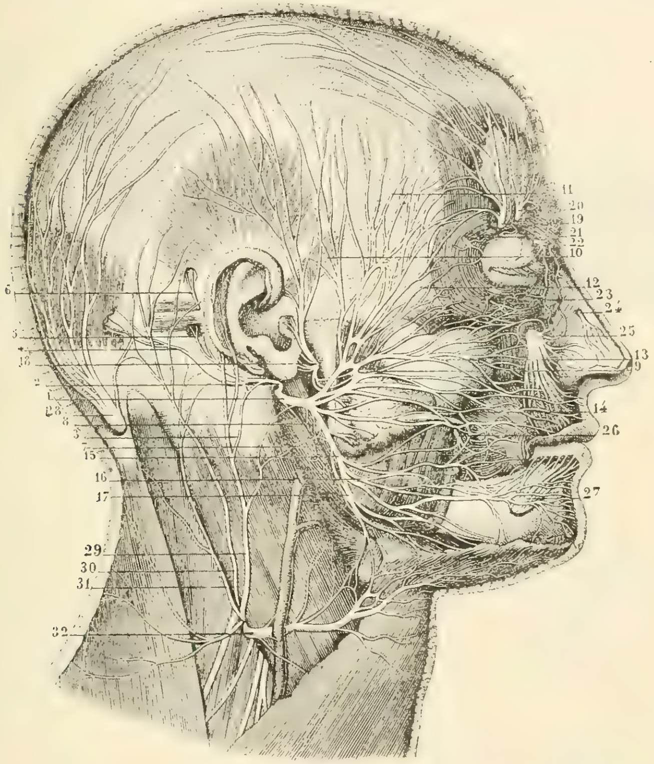

FIG. 279.—SUPERFICIAL BRANCHES OF THE FACIAL AND THE FIFTH.—1. Trunk of the facial. 2. Posterior auricular nerve. 3. Branch which it receives from the cervical plexus. 4. Occipital branch. 5, 6. Branches to the muscles of the ear. 7. Digastric branches. 8. Branch to the stylo-hyoid muscle. 9. Superior terminal branch. 10. Temporal branches. 11. Frontal branches. 12. Branches to the orbicularis palpebrarum. 13. Nasal or suborbital branches. 14. Buccal branches. 15. Inferior terminal branch. 16. Mental branches. 17. Cervical branches. 18. Superficial temporal nerve (branch of the fifth). 19, 20. Frontal nerves (branches of the fifth). 21, 22, 23, 24, 25, 26, 27. Branches of the fifth. 28, 29, 30, 31, 32. Branches of the cervical nerves. —(*Hirschfeld.*)

temporo-facial and the cervico-facial, the ultimate branches of which are distributed as previously stated to the superficial muscles of the head and face (Fig. 279).

The Pars Intermedia or Nerve of Wrisberg.—The facial nerve at the genu, the point where it turns backward to enter the aqueduct of Fallopius, presents a slight enlargement, grayish in color, and in which nerve-cells are contained. This enlargement is known as the geniculate ganglion. The cells of this ganglion, originally bipolar, present single axons which soon divide into centrally and peripherally coursing branches. The former collectively constitute the **pars intermedia** or nerve of Wrisberg, which, entering and passing through the pons, terminates around the sensor end-nucleus of the glosso-pharyngeal nerve; the latter, the peripherally directed branches, enter the sheath of the facial and accompany it as far as a point about five millimeters above the stylo-mastoid foramen.

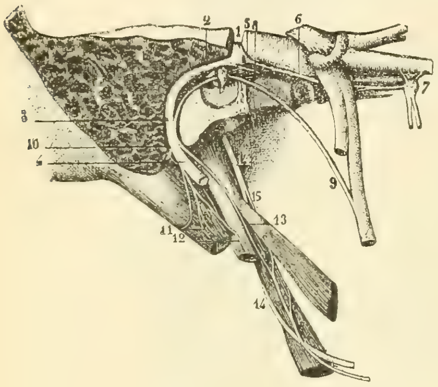

FIG. 280.—CHORDA TYMPANI NERVE. 1, 2 3, 4. Facial nerve passing through the aqueductus Fallopii. 5. Ganglioform enlargement. 6. Great petrosal nerve. 7. Sphenopalatine ganglion. 8. Small petrosal nerve. 9. Chorda tympani. 10, 11, 12, 13. Various branches of the facial. 14, 14, 15. Glosso-pharyngeal nerve.—(*Hirschfeld.*)

From its mode of origin the nerve of Wrisberg can not be regarded as an integral part of the facial nerve proper, but is to be regarded as an independent sensor nerve. As to the true function and relation of this nerve there is much conflict of opinion.

Branches of the Facial.—In the aqueduct of Fallopius the facial gives off the following branches: the greater and lesser petrosals, the stapedius, and the chorda tympani (Fig. 280).

1. The *greater petrosal* nerve is given off near the geniculate ganglion. It then passes forward into the spheno-maxillary fossa and terminates in the spheno-palatine ganglion by an arborization of its fibers around the ganglion cells.
2. The *lesser petrosal* nerve is given off at a point somewhat external to the preceding. It leaves the skull by a small foramen and terminates in the otic ganglion by an arborization of its fibers around the ganglion cells.
3. The *stapedius* branch leaves the aqueduct of Fallopius somewhat further down by a small foramen, enters the pyramid of the middle ear, and is finally distributed to the stapedius muscle.
4. The *chorda tympani* is given off from the facial at a point about five millimeters above the stylo-mastoid foramen. It then passes

upward and forward and enters the tympanum through the iter chordæ posterius, crosses the tympanic membrane between the malleus and incus, leaves the tympanum by the iter chordæ anterius or canal of Huguier, and finally joins the lingual branch of the fifth. Some of its fibers can be traced to the dorsum of the tongue, others to the submaxillary and sublingual ganglia, where they terminate in tufts around the ganglion cells.

Properties.—*Electric stimulation* of the trunk of the nerve after its emergence from the stylo-mastoid foramen produces convulsive movements in all the muscles to which its branches are distributed. The same results follow stimulation of the intra-cranial portion of the nerve in an animal recently killed.

Irritative pathologic lesions—*e. g.*, tumors, aneurysms, etc.—situated along the course of the nerve or at its nuclear origin, frequently give rise to spasmodic movements of the facial muscles which may be tonic or clonic in character.

Division of the facial nerve after its emergence from the stylo-mastoid foramen is followed by a complete relaxation or paralysis of the superficial facial muscles. The same result follows compression of the nerve-trunk in any part of its intra-cranial course.

The phenomena presented by an individual suffering from division or compression of the facial nerve, and which collectively constitute *facial paralysis*, are as follows: A relaxed and immobile condition of the side of the face corresponding to the lesion; separation of the eyelids from paralysis of the orbicularis palpebrarum and the unopposed contraction of the levator palpebræ muscles; abolition of the act of winking; drooping of the angle of the mouth; an escape of saliva from the mouth; contraction of the muscles and distortion of the opposite side of the face; on attempting to laugh or talk the distortion of the face is increased; during mastication the food accumulates between the teeth and cheek, from paralysis of the buccinator; articulation is impaired from paralysis of the orbicularis oris muscle, the labial sounds especially being imperfectly produced.

Properties of the Branches Given off in the Aqueduct of Fallopius.—The *great petrosal* nerve is in all probability composed of efferent fibers (vaso-dilatator and secretor) which leave the pons by way of the nerve of Wrisberg, or pars intermedia, to be distributed around the cells of the spheno-palatine ganglion; for stimulation either of this nerve or of the ganglion is followed by the same results: viz., dilatation of the blood-vessels of, and secretion from, the mucous membrane of the nose, soft palate, upper part of the pharynx, roof of mouth, gums, and upper lip.

The *small petrosal* nerve is also composed of efferent fibers; shortly after leaving the facial it is joined by a small nerve, derived from Jacobson's branch of the glosso-pharyngeal, which is also efferent in function; for stimulation of Jacobson's nerve as well as stimulation of the otic ganglion is followed by the same result: viz., dilatation of the blood-vessels of, and secretion from, the mucous membrane of the cheek, lower lip, and gums, and of the parotid and the orbit glands.

The *stapedius* nerve, distributed directly to the stapedius muscle, is motor in function.

The Chorda Tympani.—Stimulation of the chorda tympani nerve in the tympanic cavity produces dilatation of the blood-vessels of, and an increased production and discharge of saliva from, the submaxillary and sublingual glands.

Division of this nerve is followed by a contraction of the blood-vessels and a diminution of the secretion. From these results it is certain that the chorda tympani contains both vaso-dilatator and secretor fibers. Nicotin applied to the submaxillary and sublingual ganglia abolishes the effects of stimulation of the chorda tympani. It does not prevent the same effects when the ganglia themselves are stimulated. It is clear, therefore, that the vaso-dilatator and secretor fibers arborize around the cells of the ganglia and are not distributed directly to the gland structures. It is highly probable that the efferent fibers in the chorda tympani emerge from the pons by way of the pars intermedia, or nerve of Wrisberg.

Division of the chorda in the tympanum is also followed by a loss of taste in the anterior two-thirds of the tongue. For this and other reasons the chorda tympani has long been regarded as the nerve of taste for this region. The specific physiologic stimulus to the chorda tympani nerve is organic matter in solution acting on the peripheral terminations of the nerve in the mucous membrane of the tongue. The exact pathway for these *afferent* or gustatory fibers beyond the geniculate ganglion has long been a subject of much discussion. According to some observers these fibers enter the great petrosal nerve, pass forward as far as the spheno-palatine ganglion, then into the superior maxillary division of the trigeminal, and so to the brain. According to others, these fibers pass into the pars intermedia, into the pons, where they terminate around the sensor end-nucleus of the glosso-pharyngeal. The evidence for and against either of these two views is most conflicting and insufficient to justify positive statements one way or the other. To the writer the weight of evidence seems to favor the view that the gustatory fibers have their origin in the geniculate ganglion; that they pass centrally through the pars intermedia; that they are similar in function to the glosso-pharyngeal; and that they are indeed but aberrant branches of this nerve.

Functions.—The function of the facial nerve is the transmission of nerve impulses from the nerve-cells from which it arises to the muscles of the face. As these muscles express ideas and emotions the nerve has been termed the nerve of expression. Because of the presence of efferent fibers which leave the main trunk by way of the chorda tympani nerve, it regulates the caliber of the blood-vessels of the submaxillary and sublingual glands and excites the glands to activity. It also influences hearing by its action on the stapedius muscle.

EIGHTH PAIR. THE AUDITORY.

The eighth cranial nerve, the auditory, consists of the centrally coursing axons of neurons which connect the essential organ of hearing with sensor end-nuclei in the pons Varolii. This nerve consists of two portions: viz., a *cochlear* or auditory and a *vestibular* or equilibratory.

Origin.—The axons comprising the cochlear portion have their origin in the bipolar nerve-cells of the spiral ganglion located in the spiral canal near the base of the osseous lamina spiralis (Fig. 281). From this origin they pass centrally into the central canal of the modiolus, at the base of which they emerge in well-defined bundles and enter the internal auditory meatus. Dendritic processes from these cells pass peripherally to terminate on the ciliated epithelial cells of the organ of Corti.

The axons comprising the vestibular portion have their origin in the bipolar nerve-cells of the ganglion of Scarpa located in the internal auditory meatus. From this origin they pass centrally in connection with the cochlear portion. Dendritic processes from these cells pass peripherally into the internal ear, where they terminate on epithelial cells situated on the inner surface of the utricle and saccule and in the ampullæ of the semicircular canals.

The common trunk of the auditory nerve, consisting of both cochlear and vestibular divisions after emerging from the internal auditory meatus, passes backward, inward, and downward as far as the lateral aspect of the pons where the two divisions again separate.

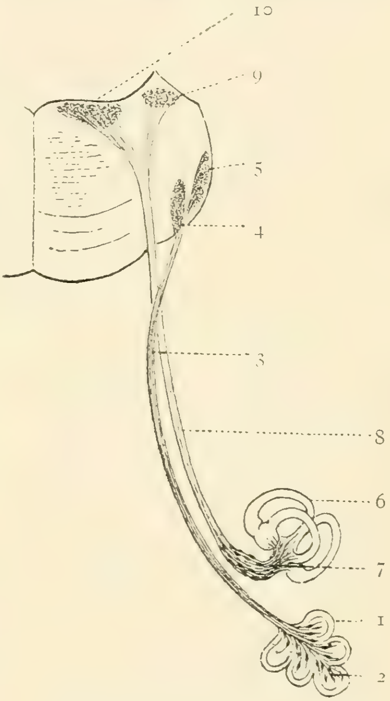

FIG. 281.—ORIGIN AND TERMINATION OF THE AUDITORY NERVE. 1. Cochlea. 2. Spiral ganglion (Corti). 3. Cochlear nerve. 4. Ventral acoustic nucleus. 5. Lateral acoustic nucleus. 6. Semicircular canals. 7. Ganglion of Scarpa. 8. Vestibular nerve. 9. Dorso-external nucleus (Deiters). 10. Dorso-internal nucleus.—(*After Morat and Doyon.*)

The cochlear nerve, the external root, passes to the outer side of the restiform body and enters the ventral acoustic nucleus and the lateral acoustic nucleus, around the cells of which its end-tufts arborize. The vestibular nerve, the internal root, passes on the inner side of the restiform body to the dorsal portion of the pons, where, after bifurcating, the end-tufts of the axons arborize around the dorso-internal or chief auditory nucleus and the dorso-external or Deiters' nucleus. Some of the fibers of the vestibular branch descend through the pons and medulla as far as the cuneate nucleus.

Cortical Connections.—The cochlear nerve is ultimately connected with the cerebral acoustic area, in the temporal lobe of the opposite side through the intermediation of the auditory tract. This tract is complex and involved. In a general way it may be said to consist in part of fibers which come direct from the cochlear branch. After passing through the ventral nucleus and the trapezoid body they cross the median line, enter the lemniscus or fillet, and finally terminate in the pre- and post-geminal bodies. In their course they give off collateral branches to these various nuclei through which they pass. Other fibers taking their origin from cells in these various nuclei proceed to the cortex where they terminate.

Properties.—Stimulation of the cochlear nerve is unattended by either motor or sensor phenomena. *Division* of the nerve is followed by a loss of the sense of hearing. Irritative pathologic lesions give rise to sensations of sound of varying character and intensity. Degeneration of the nerve or destruction by tumors, etc., will also be followed by a loss of the sense of hearing.

Experimental lesions of the semicircular canals involving a destruction of the physiologic relations of the *vestibular* nerve are followed by a loss of the coördinating and equilibratory power. Disordered movements, such as rotation to the right or left, somersaults backward and forward, follow destruction of these canals. Pathologic lesions in the peripheral distribution of the nerve are attended in man by disturbances of equilibrium, *e. g.*, vertigo, a sense of swaying, pitching, and staggering.

Functions.—The function of the cochlear nerve is to convey nerve impulses from its origin to the pons, from which they are transmitted by the auditory tract to the acoustic area in the cerebral cortex where they evoke sensations of sound and its different qualities, intensity, pitch and timbre. The specific physiologic stimulus to the development of these impulses is the impact of atmospheric undulations on the tympanic membrane, received and transmitted by the chain of bones to the structures of the internal ear—the organ of Corti—with which the peripheral terminations of the nerve are connected.

The function of the vestibular nerve is the transmission of nerve impulses to the pons, whence they are transmitted to the cortex of both the cerebrum and cerebellum and to other centers. The specific physiologic stimulus is supposed to be a variation in pressure in the ampullæ of the semicircular canals caused by movements of the endolymph induced by changes in the position of the head and body. The impulses carried by the vestibular nerve give rise reflexly to certain adaptive and protective movements by which the equilibrium of the body in both dynamic and static conditions is maintained.

NINTH NERVE. THE GLOSSO-PHARYNGEAL.

The ninth cranial nerve, the glosso-pharyngeal, consists, as shown by both histologic and experimental methods of research, of both afferent and efferent nerve-fibers, of which the former, however, are by far the more abundant. Near its exit from the cavity of the skull the nerve presents two ganglionic enlargements known as the *petrosal* and *jugular* ganglia.

Origin of the Afferent Fibers.—The afferent fibers serve to bring certain end-nuclei in the medulla oblongata into anatomic and physiologic relation with portions of the mucous membrane of the tongue, pharynx, and middle ear. The afferent fibers are axons of the monaxonic cells of the petrosal and jugular ganglia. The single axon from each of these cells soon divides into two branches, one of which passes centrally, the other peripherally. The centrally directed branches collectively form the so-called roots, four or five in number, which enter the medulla between the olivary and restiform bodies. The peripherally directed branches collectively form the two main divisions, from the distribution of which, to the tongue and pharynx, the nerve takes its name.

Distribution.—The axons of the centrally directed branches after entering the medulla pass toward its dorsal aspect, where they bifurcate, give off collateral branches, and terminate in fine end-tufts in the immediate neighborhood of two groups of nerve-cells, the *sensor end-nuclei.* The axons of the peripherally directed branches, after emerging from the base of the skull through the jugular foramen, pass forward and inward under cover of the stylo-pharyngeal muscle; winding around this muscle they divide into terminal branches which are distributed to the mucous membrane of the posterior one-third of the tongue, pharynx, soft palate, uvula, and tonsils (Fig. 283).

Origin of the Efferent Fibers.—The efferent fibers serve to bring the nerve-cells from which they arise into connection with a portion of the musculature of the fauces and pharynx. These nerve-cells are located in the lateral portion of the *formatio reticularis* at some distance below the floor of the fourth ventricle. They constitute the upper portion of a collection of cells known as the *nucleus ambiguus.*

Distribution.—From this origin the efferent fibers pass dorsally to near the sensor end-nuclei, then turn outward and forward and finally emerge from the medulla in intimate association with the afferent fibers. They are ultimately distributed to the stylo-pharyngeus, the palato-glossus and to the middle constrictor muscles of the pharynx. In addition to the foregoing efferent fibers the glosso-pharyngeal nerve contains at its emergence from the medulla both vaso-motor and secretor fibers.

Jacobson's Nerve.—This is a small branch which leaves the glosso-pharyngeal at the petrous ganglion. After passing through a small canal in the base of the skull it enters the tympanic cavity, within which it gives off branches to the great and lesser petrosal nerves, to the mucous membrane of the foramen ovale, the foramen rotundum, and to the Eustachian tube.

Cortical Connections.—The *motor* nucleus is doubtless connected with the general motor area of the cortex through fibers descending in the pyramidal tract. The exact location of the cortical area for the pharynx is not well determined, but is most likely to be found in the lower part of the general motor area near the termination of the Rolandic fissure. The exact cortical connections of the afferent tract are unknown, but are most likely to be found in the general sensor area.

Properties.—Electric stimulation of the glosso-pharyngeal trunk calls forth evidence of pain and contraction of the stylo-pharyngeus and middle constrictor muscles. Peripheral stimulation of the terminals of the nerve fibers in the mucous membrane of the posterior third of the tongue with different kinds of organic matter in solution, develops nerve impulses which transmitted to the cortex evoke sensations of taste. Division of the nerve abolishes sensibility in the mucous membrane to which it is distributed, impairs the sense of taste in the posterior third of the tongue, and gives rise to paralysis of the above-mentioned muscles.

Stimulation of Jacobson's nerve is followed by dilatation of the blood-vessels of, and secretion from, the mucous membrane of the lower lip, cheek, and gums, and from the parotid gland. Division of the nerve is followed by the opposite results. The course of the fibers which give rise to these results is by way of the lesser petrosal to the otic ganglion, around the cells of which the fibers arborize. From the cells of this ganglion non-medullated fibers pass to the blood-vessels and gland cells.

Functions.—The afferent fibers of the glosso-pharyngeal transmit nerve impulses from the parts to which they are distributed to the cerebral cortex, where they evoke sensations of pain and sensations of taste; they also assist in all probability in the performance of certain reflexes connected with deglutition. The efferent fibers transmit impulses to muscles, exciting them to activity, and to the otic ganglion, which in turn dilates blood-vessels and excites secretion.

TENTH NERVE. THE PNEUMOGASTRIC OR VAGUS.

The tenth cranial nerve, the pneumogastric or vagus, consists, as shown by histologic methods of research, of both afferent and efferent fibers, independent of those derived in its course from adjoining motor or efferent nerves. Near the exit of the nerve from the cavity of the cranium it presents two ganglionic enlargements known respectively as the ganglion of the root (the jugular) and the ganglion of the trunk (the plexiform).

Origin of the Afferent Fibers.—The afferent fibers take their origin in the monaxonic cells of the ganglia on the root and trunk. The single axon from each of these cells soon divides into two branches, one of which passes centrally, the other peripherally. The centrally directed branches collectively form the so-called roots, ten to fifteen in number, which enter the medulla between the restiform body and the lateral column. The peripherally directed branches collectively form a portion of the common trunk of the nerve.

Distribution.—The axons of the centrally directed branches after entering the medulla pass toward its dorsal aspect, where they bifurcate, give off collaterals, and terminate in fine end-tufts in the immediate neighborhood of two groups of nerve-cells, the *vagal sensor end-nuclei.*

The axons of the peripherally directed branches unite to form a portion of the common trunk, which, as it descends the neck and enters the thorax and abdomen, gives off a number of branches which are ultimately distributed to the mucous membrane of the esophagus, larynx, lungs, stomach, and intestine, and also to the heart. The afferent fibers thus serve to bring into anatomic and physiologic relation the mucous membrane of these organs with certain sensor end-nuclei in the medulla oblongata.

Origin of the Efferent Fibers.—The efferent fibers take their origin from nerve-cells located in the lateral portion of the *formatio reticularis* at some distance below the floor of the fourth ventricle. These cells constitute the lower portion of the *nucleus ambiguus.*

Distribution.—From their origin the efferent axons pass dorsally to near the sensor end-nuclei, then turn outward and forward, and finally emerge from the medulla in close association with the afferent branches. They are ultimately distributed to the levator palati, azygos uvulæ, and palato-pharyngeus muscles; to the superior and inferior constrictor muscles of the pharynx, and to the muscles of the esophagus; to the muscle-fibers of the stomach and perhaps the intestines; and to the non-striated muscle-fibers of the bronchial tubes. Among the efferent fibers are some which are distributed to the gastric glands and to the pancreas.

According to Beevor and Horsley, in the monkey the motor fibers for the levator palati come from the spinal accessory nerve.

The efferent fibers thus serve to bring the nerve-cells from which they arise into anatomic and physiologic connection with a portion of the musculature of the alimentary canal and its diverticulum, the lung.

Communicating Branches.—At or near the ganglia the vagus receives communicating branches from the eleventh nerve, the spinal accessory, the facial, the hypoglossal, and the anterior branches of the two upper cervical nerves. Owing to this manifold origin of the efferent fibers in the trunk and peripheral branches of the vagus, it is, in some instances, difficult, if not impossible, to determine to which of these nerves a given muscle contraction is to be referred.

Vagal Branches.—As the vagus passes down the neck it gives off the following main branches (Fig. 282):

1. The *pharyngeal nerves* which, after entering into the formation of the pharyngeal plexus, are distributed to the mucous membrane and to the muscles of the pharynx; *e. g.*, superior and inferior constrictors, the levator palati, and the azygos uvulæ.

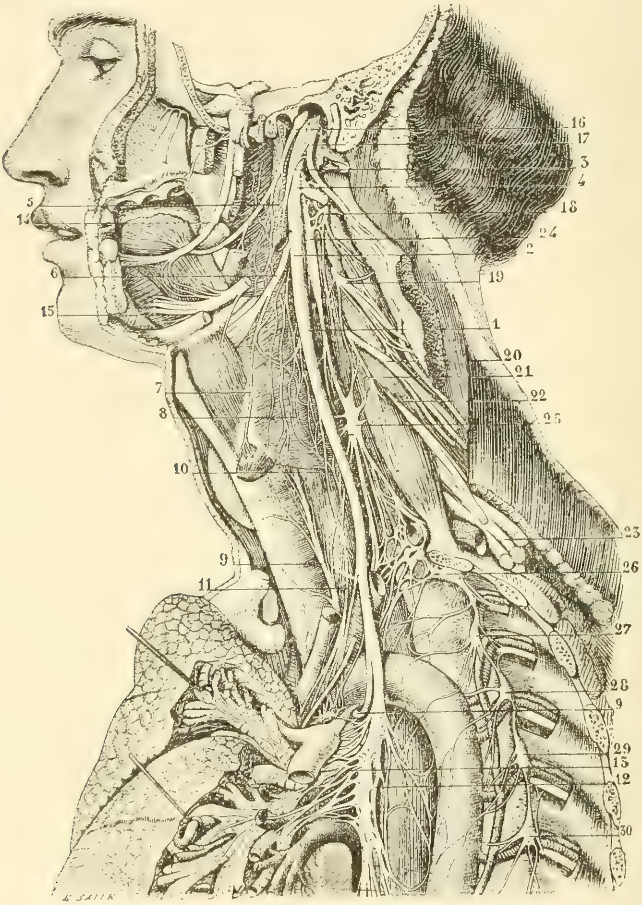

FIG. 282.—DISTRIBUTION OF THE PNEUMOGASTRIC.—1. Trunk of the left pneumogastric. 2. Ganglion of the trunk. 3. Anastomosis with the spinal accessory. 4. Anastomosis with the sublingual. 5. Pharyngeal branch (the auricular branch is not shown in the figure). 6. Superior laryngeal branch. 7. External laryngeal nerve. 8. Laryngeal plexus. 9, 9. Inferior laryngeal branch. 10. Cervical cardiac branch. 11. Thoracic cardiac branch. 12, 13. Pulmonary branches. 14. Lingual branch of the fifth. 15. Lower portion of the sublingual. 16. Glosso-pharyngeal. 17. Spinal accessory. 18, 19, 20. Spinal nerves. 21. Phrenic nerve. 22, 23. Spinal nerves. 24, 25, 26, 27, 28, 29, 30. Sympathetic ganglia.—(*Hirschfeld.*)

2. The *esophageal nerves*, which after entering into the formation of

the esophageal plexus, are distributed to the mucous membrane, and to the muscles of the esophagus.

3. The *superior laryngeal nerve* which, entering the larynx through the thyro-hyoid membrane, is distributed to the mucous membrane lining the interior of the larynx and to the crico-thyroid muscle. From the superior laryngeal and the main trunk small branches are given off which in the rabbit unite to form a single nerve, the so-called *depressor nerve.* (See page 380.) It is distributed to the heart-muscle. Though this anatomic arrangement is not found in man, there are many reasons for believing that analogous fibers are present in the vagus trunk of man and other animals.
4. The *inferior laryngeal nerve* which is distributed ultimately to all the muscles of the larynx (except the crico-thyroid) and to the inferior constrictor of the pharynx.
5. The *cardiac nerves* which, after entering into the formation of the cardiac plexus, are distributed to the heart.
6. The *pulmonary nerves* distributed to the mucous membrane of the bronchial tubes and their ultimate terminations, the lobules and air-cells, as well as to their non-striated muscle-fibers.
7. The *gastric and intestinal nerves*, distributed to the mucous membrane and muscular walls of the stomach and intestines. Other fibers in all probability pass to the liver, spleen, kidney, and suprarenal bodies.

Properties of the Pneumogastric or Vagus Nerve and its Various Branches.—*Faradization* of the vagus nerve close to the medulla oblongata gives rise to sensations of pain and to contraction of the musculature of a portion of the alimentary tract: viz., the palate, pharynx, esophagus, stomach, and possibly of the intestine and of the pulmonary apparatus. *Division* of the nerve is followed by a loss of sensibility in the mucous membrane of the alimentary tract and of the pulmonary apparatus, together with a loss of motility of the structures above mentioned.

Stimulation of the trunk of the nerve in different parts of its course produces a variety of results dependent to some extent on the presence of anastomosing branches from adjoining nerves.

The Pharyngeal Nerves.—Faradization of the pharyngeal nerves consisting of both afferent and efferent fibers, gives rise to sensations of pain, contraction of the pharyngeal muscles, and perhaps to vomiting. Division of these nerves is followed by a loss of sensibility in the parts to which they are distributed and by paralysis of the muscles with a consequent impairment of deglutition.

The Esophageal Nerves.—Faradization of the esophageal nerves gives rise to sensations of pain and to contractions of the muscle coat of the esophagus. Division of these nerves is followed by a loss of sensibility in the parts to which they are distributed, a partial paralysis of the muscle coat and an impairment of deglutition (see page 170).

The Superior Laryngeal Nerve.—Faradization of the superior laryngeal nerve gives rise to sensations of pain, and to contraction of the crico-thyroid muscle. Through reflected impulses it causes contraction of the muscles of deglutition, and of the muscles concerned in the act of coughing; inhibition of the inspiratory movement and arrest of respiration in the condition of expiratory standstill, with perhaps a tetanic contraction of the expiratory muscles, and contraction of the laryngeal muscles with closure of the glottis. Peripheral stimulation of this nerve—*e. g.*, the contact of foreign particles—gives rise to a similar series of phenomena. Division of these nerves is followed by a loss of sensibility in the laryngeal mucous membrane, paralysis of the crico-thyroid muscle with a consequent lowering of the pitch, and a diminution in the clearness of the voice. In consequence of the loss of the sensibility there is an inability to perceive the entrance of foreign bodies into the larynx.

The Depressor Nerve.—Stimulation of the peripheral end of the depressor nerve is without effect; stimulation of the central end retards and even arrests the heart's pulsations and lowers the general blood-pressure. These two effects, though associated, are nevertheless independent of each other. If the vagus nerves be divided on both sides between the origin of the depressor and the origin of the cardiac nerves, and the former stimulated, there will be a fall of pressure without retardation of the heart. The effect on the heart is attributed to a stimulation of the cardio-inhibitory mechanism in the medulla oblongata.

The fall of general blood-pressure was formerly attributed to a sudden dilatation of the splanchnic blood-vessels alone, in consequence of a depression of that portion of the general vaso-motor center which maintains through the splanchnic nerves a tonic contraction of their walls. It has been satisfactorily demonstrated that this is not the sole cause; for after division of the splanchnic nerves, stimulation of the depressor causes a still further fall of from 30 to 40 per cent. in the general pressure (Porter and Beyer). Evidently, not any one, but all portions of the vaso-motor center are subject to the effects of depressor stimulation.

The Inferior Laryngeal Nerves.—Faradization of the inferior laryngeal nerves produces effects which vary in accordance with the strength of the stimulus, with different animals, and with the same animal at different periods of life. In the adult dog and in man, the glottis is kept widely open for respiratory purposes by the tonic contraction of the abductor muscles (the crico-arytenoids); for phonatory purposes the glottis is closed and the vocal membranes approximated by the contraction of the adductor muscles. It has been shown that these opposed groups of muscles have independent nerve-supplies; that two sets of fibers in the common trunk can be separated and stimulated independently of each other. *Feeble* stimulation of the common trunk produces a still further abduction of the vocal cords.

With an increase in the strength of the stimulus, however, the reverse obtains: namely, adduction which increases until the glottis is completely closed. Division of the nerves is followed by paralysis of both the phonatory and respiratory muscles, the abductors and adductors, with the result of seriously impairing both phonation and respiration and not infrequently causing death. The fibers of the inferior laryngeal nerve are derived from the eleventh nerve, the spinal accessory.

The Cardiac Nerves.—Faradization of the trunk of the vagus or of the peripheral end of the divided nerve gives rise to a diminution in the frequency and force of the heart's contractions; and if the stimulation be sufficiently powerful, completely arrests it in the phase of diastole. To these results the term inhibition is applied. Division of the vagi or of the cardiac branches is followed by an increase in the number of contractions from loss of inhibitor influences. The inhibitor fibers of the vagus are generally believed to be derived from the spinal accessory, though this has been questioned. According to the recent investigations of Schaternikoff and Friedenthal, they come direct in the vagus, from a nucleus near the vagal motor nucleus in the medulla, the spinal accessory sending no branches to the heart. In the frog and other batrachia the vagus contains also accelerator or augmentor fibers derived from the sympathetic; hence stimulation, especially if feeble, may increase the heart's action.

The Pulmonary Nerves.—The pulmonary nerves, given off from the trunk after its entrance into the thorax, do not lend themselves readily to experimentation. Division of both vagi in the neck above the point of exit of the pulmonary branches is followed by a decrease in the frequency of the respiratory acts, with an increase in their depth. At the same time there is a loss of sensibility of the mucous membrane of the trachea and lungs and a paralysis of non-striated muscle-fibers.

Stimulation of the central end of the vagus increases the frequency, but decreases the amplitude, of the respiratory movements. If the stimulation be increased in intensity the respiratory movements increase in frequency until the inspiratory muscles pass into the condition of tetanus.

Feeble stimulation of the vagus not infrequently inhibits the inspiratory movement and increases the expiratory until there is a complete cessation of movement in the condition of expiratory standstill. The effect thus produced is similar to, if not identical with, that produced by stimulation of the superior laryngeal nerve. This would seem to indicate the presence in the vagus trunk of two sets of afferent fibers coming from the lungs through the pulmonary branches, one of which inhibits inspiration, the other inhibits expiration.

Faradization of the trunks of the pulmonary branches or stimulation of their peripheral terminations in the mucous membrane of the bronchial tubes or alveoli by the inhalation of chemic vapors causes arrest of respiratory movements, a fall of blood-pressure, and a reflex inhibition of the heart (Brodie).

Gastric Nerves.—Stimulation of the peripheral end of a divided vagus nerve causes a distinct contraction of the right half of the stomach and secretion from the gastric glands. Division of the nerve abolishes the sensibility of the mucous membrane of the stomach, impairs motility, and interferes with the secretion of the gastric juice.

Similar experimentation on the trunk of the vagus has shown that the nerve excites contraction of the upper part of the small intestine and of the gall-bladder, the secretion of the pancreas, the renal circulation, the secretion of urine, etc.

Functions.—The afferent fibers transmit nerve impulses from the area of their distribution to the medulla and thence through cortical connections to the sensor cerebral areas, where they evoke sensations. They therefore endow all parts to which they are distributed with sensibility.

The efferent fibers transmit impulses outward which excite contraction of the muscles of the pharynx, the esophagus, the stomach, the small intestine, and the gall-bladder, and the muscles of the bronchial tubes; excite secretion from the glands of the stomach, pancreas, and kidney and exert an inhibitor influence on the activity of the heart. The efferent fibers belong to the autonomic system of nerves and are not connected with the ganglia of the vagus, but with local peripheral ganglia.

The afferent fibers also assist in the maintenance of certain organic reflex actions which are highly essential to the life of the individual, *e. g.*, respiration, the heart beat, blood pressure, etc., all of which have been considered in foregoing pages.

ELEVENTH PAIR. THE SPINAL ACCESSORY.

The eleventh cranial nerve, the spinal accessory, consists of peripherally coursing fibers which bring the nerve-cells from which they arise into relation with separate but functionally related muscles. It consists of two portions, the medullary or bulbar and the spinal.

Origin.—The axons comprising the *medullary* portion arise from a group of nerve-cells in the lower part of the nucleus ambiguus. From this origin the axons pass forward and outward to emerge from the medulla just below and in series with the roots of the vagus nerve.

The axons comprising the spinal portion have their origin in nerve-cells in the lateral margin of the anterior horn of the gray matter in the cervical portion of the cord as far down as the fifth cervical vertebra. From this origin the fibers pass to the surface of the cord to emerge between the ventral and dorsal roots in from six to eight filaments, after which they unite from below upward to form a distinct nerve. This enters the cranial cavity through the foramen magnum, where it joins with the medullary portion to form the common trunk, which then passes forward to emerge from the cranium through the jugular foramen. (Fig. 283.)

Distribution.—After emerging from the cranial cavity the nerve soon separates into two branches:

1. An *internal* or *anastomotic* branch, consisting chiefly of filaments coming from the medulla oblongata. It soon enters the trunk of the vagus, from which fibers pass to the muscles of the pharynx, to the muscles of the larynx through the inferior laryngeal nerve, and to the heart according to most authorities.
2. An *external* branch, consisting chiefly of the accessory fibers from the spinal cord.

It is distributed to the sterno-cleido-mastoid and trapezius muscles.

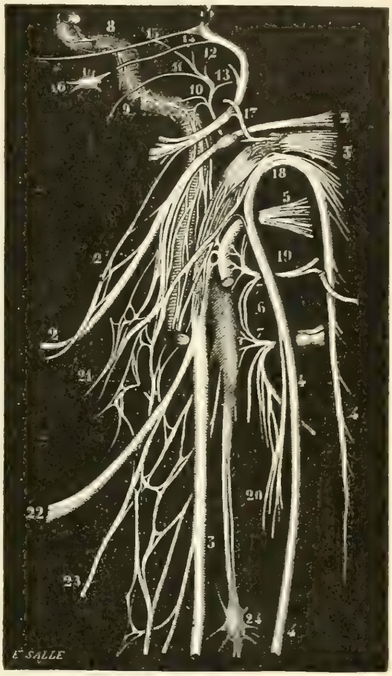

FIG. 283.—SPINAL ACCESSORY NERVE. 1. Trunk of the facial nerve. 2, 2. Glosso-pharyngeal nerve. 3, 3 Pneumogastric. 4, 4, 4. Trunk of the spinal accessory. 5. Sublingual nerve. 6. Superior cervical ganglion. 7, 7. Anastomosis of the first two cervical nerves. 8. Carotid branch of the sympathetic. 9, 10, 11, 12, 13. Branches of the glosso-pharyngeal. 14, 15. Branches of the facial. 16. Otic ganglion. 17. Auricular branch of the pneumogastric. 18. Anastomosing branch from the spinal accessory to the pneumogastric. 19. Anastomosis of the first pair of cervical nerves with the sublingual. 20. Anastomosis of the spinal accessory with the second pair of cervical nerves. 21. Pharyngeal plexus. 22. Superior laryngeal nerve. 23. External laryngeal nerve. 24. Middle cervical ganglion.—(*Hirschfeld.*)

Cortical Connections.—The nucleus of origin of the medullary branch at least is in relation with nerve-cells in the lower third of the general cerebral motor area, the axons of which descend in the pyramidal tract.

Properties. — Faradization of the medullary portion of the nerve near its origin gives rise to contraction of the muscles to which they are distributed. Destruction of the medullary root is followed by impairment of deglutition and a loss of the power of producing vocal sounds on account of paralysis of the constrictor muscles of the larynx. According to some authorities, there is also an acceleration of the heart's action from a loss of inhibitor influences.

Stimulation of the external branch gives rise to contraction of the sterno-cleido-mastoid and trapezius muscles, though division of the branch does not give rise to complete paralysis, as they are supplied with motor fibers also from the cervical nerves. In consequence of division of the external branch animals experience extreme shortness of breath during exercise, from a want of coördination of the muscles of the fore-limbs and the muscles of respiration.

Functions.—The function of the fibers of the spinal accessory nerve is the transmission of nerve impulses from the cells from which they take their origin to the muscles to which they are distributed. They therefore excite to action some of the muscles of deglutition; the muscles which regulate the tension of the vocal bands during phonation and the muscles which control the respiratory movements associated with sustained or prolonged muscle efforts. The fibers also convey nerve impulses which exert an inhibitor influence on the heart.

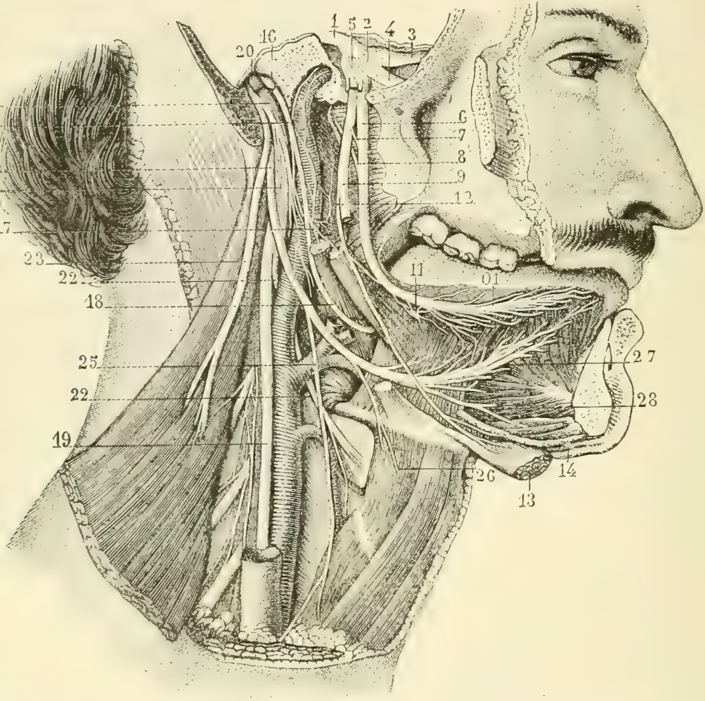

FIG. 284.—DISTRIBUTION OF THE HYPOGLOSSAL NERVE.—1. Root of the fifth nerve. 2. Ganglion of Gasser. 3, 4, 5, 6, 7, 9, 10, 12. Branches and anastomoses of the fifth nerve. 11. Submaxillary ganglion. 13. Anterior belly of the digastric muscle. 14. Section of the mylo-hyoid muscle. 15. GLOSSO-PHARYNGEAL NERVE. 16. Ganglion of Andersch. 17, 18. Branches of the glosso-pharyngeal nerve. 19, 19. Pneumogastric. 20, 21. Ganglia of the pneumogastric. 22, 22. Superior laryngeal branch of the pneumogastric. 23. Spinal accessory nerve. 24. Sublingual nerve. 25. Descendens noni. 6. Thyro-hyoid branch. 27. Terminal branches. 28. Two branches one to the genio-hyo-glossus and the other to the genio-hyoid muscle.—(*Sappey.*)

TWELFTH PAIR. THE HYPOGLOSSAL.

The twelfth cranial nerve, the hypoglossal, consists of peripherally coursing nerve-fibers which serve to connect the nerve-cells from which they arise with the musculature of the tongue.

Origin.—The axons composing the hypoglossal nerve arise from a collection of nerve-cells situated beneath the floor of the fourth ventricle. This nucleus is elongated and extends from the medullary striæ downward as far as the lower border of the olivary body. It is located ventro-laterally to the spinal canal. After leaving the cells of the nucleus the axons pass forward and outward toward the surface of the medulla, from which they emerge in ten or twelve small bundles or filaments in the groove between the olivary body and the anterior pyramid. Beyond this point they unite to form a common trunk.

Distribution.—The common trunk thus formed passes out of the cranial cavity through the anterior condyloid foramen. In its course it receives filaments from the first and second cervical nerves, the sympathetic and vagus. It is finally distributed to the intrinsic muscles of the tongue and to the genio-hyo-glossus, hyo-glossus, and stylo-hyoid muscles. Branches derived from the cervical plexus pass to muscles which elevate and depress the hyoid bone. (Fig. 284.)

Cortical Connections.—The hypoglossal nerve nuclei are connected with nerve-cells in the lower third of the general motor area around the inferior termination of the fissure of Rolando by axons which descend in the pyramidal tract.

Properties.—Faradization of the nerve gives rise to convulsive movements of the muscles to which it is distributed. Division of the nerve is followed by a loss of motion and an interference with deglutition, mastication, and articulation, especially in the pronunciation of the consonantal sounds. In hemiplegia, complicated with paralysis of the tongue from injury to the hypoglossal tract, the opposite side of the tongue is involved in the paralysis. On protrusion of the tongue the tip is deviated to the paralyzed side, due to the unopposed action of the muscle of the opposite side.

Function.—The hypoglossal nerve transmits nerve impulses from its center of origin to the intrinsic and extrinsic muscles of the tongue, endowing them with motility. The coördinate activity of these muscles favorably assists mastication, articulation, and deglutition.

CHAPTER XXIV.

THE SYMPATHETIC NERVE SYSTEM.

The sympathetic nerve system consists of a number of ganglia united one to another by intervening cords of nerve-fibers. These ganglia may for convenience of description be divided into three groups: viz., the vertebral or lateral, the pre-vertebral or collateral, and the peripheral or terminal.

The *vertebral* ganglia are arranged in the form of chains, one on each side of the vertebral column. The number of ganglia in the chain varies in animals of different and in animals of the same species. In man the number varies from 20 to 22. Each chain may be divided into a cervical, a thoracic, a lumbar, a sacral, and a coccygeal portion. The cervical portion is usually described as consisting of three ganglia —a superior, a middle, and an inferior. This statement is open to question, however, as the middle one is frequently absent and the inferior one is regarded by some anatomists as belonging to the pre-vertebral series. The thoracic portion consists of ten or eleven ganglia, the lumbar and sacral portions of four each and the coccygeal portion of one, the so-called ganglion impar.

The *pre-vertebral* ganglia are also united in the form of a chain situated in the abdominal cavity. The ganglia constituting this chain are known as the semilunar, the renal, the superior and inferior mesenteric, and hypogastric.

The *peripheral* ganglia are in more or less close relation with the tissues and organs in different parts of the body. As members of this group may be mentioned the ciliary or ophthalmic, the spheno-palatine, the otic, the submaxillary and the sublingual ganglia; the ganglia in walls of the heart, the respiratory organs, the intestines, the bladder, etc.

The general arrangement of the sympathetic ganglia, their inter-connecting cords and branches, is shown in Figs. 285 and 286.

Structure of the Ganglia.—Each ganglion consists of a capsule or stroma of connective tissue in which are contained large numbers of nerve-cells, nerve-fibers, medullated and non-medullated, and blood-vessels. The nerve-cells give origin to two or more dendrites, which, perforating a nucleated capsule by which each cell is surrounded, branch and rebranch and interlace to form a pericapsular plexus. Each cell gives origin also to an axon, which as it leaves the cell becomes invested with a sheath continuous with the capsule surrounding the cell-body. It is, however, wanting in a medullary sheath, and hence the nerve presents a gray color. Such a structure, in its entirety, is known as a sympathetic neuron.

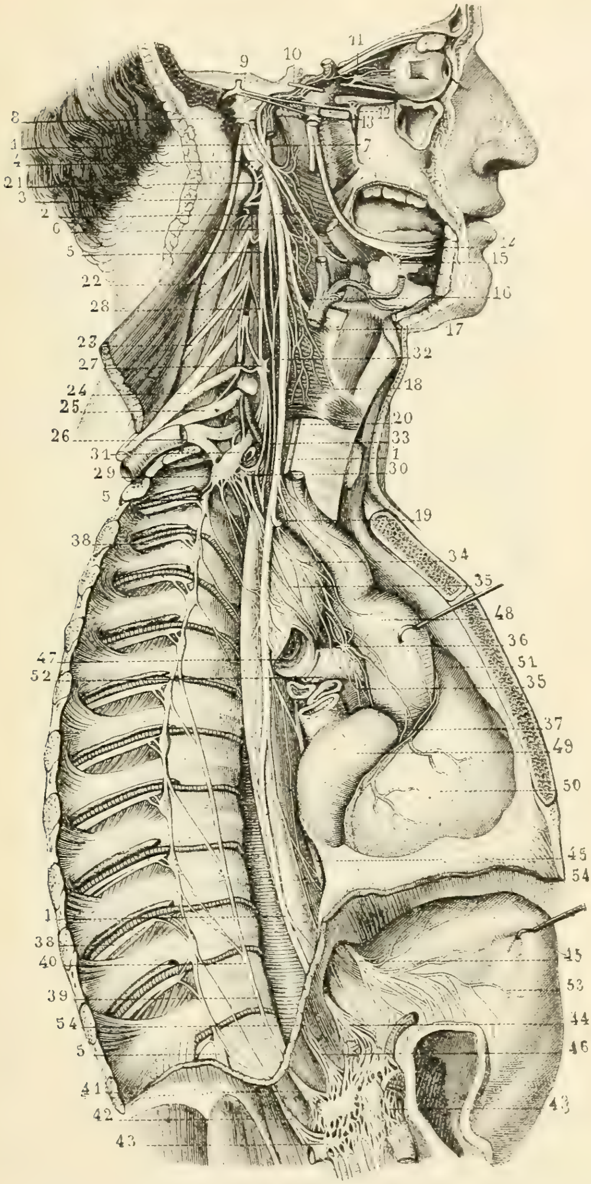
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FIG. 285.—CERVICAL AND THORACIC PORTION OF THE SYMPATHETIC. 1, 1, 1. Right pneumogastric. 2. Glosso-pharyngeal. 3. Spinal accessory. 4. Divided trunk of the sublingual. 5, 5, 5. Chain of ganglia of the sympathetic. 6. Superior cervical ganglion. 7. Branches from this ganglion to the carotid. 8. Nerve of Jacobson. 9. Two filaments from the facial, one to the spheno-palatine and the other to the otic ganglion. 10. Motor oculi externus. 11. Ophthalmic ganglion, receiving a motor filament from the motor oculi communis and a sensory filament from the nasal branch of the fifth. 12. Spheno-palatine ganglion. 13. Otic ganglion. 14. Lingual branch of the fifth nerve. 15. Sub-

Structure of the Interconnecting Cords.—The interconnecting cords are composed of non-medullated and medullated nerve-fibers. The former are the axons of cells found in the ganglia more centrally located; the latter, as will be stated later, are derived from the spinal nerves, from the fibers of which, however, they differ in character, being much smaller and finer. The fibers of the interconnecting cords, as a rule, transmit nerve impulses from the more centrally to the more peripherally located ganglia, and are therefore termed *rami efferentes*. In the vertebral chain some of the cords transmit nerve impulses upward, others downward, others again forward, to the pre-vertebral and peripheral ganglia.

Among the rami efferentes, interconnecting cords, there are some which possess special interest for the physiologist, viz.:

1. The *cervical*, which connects the thoracic ganglia with the superior cervical ganglion. It is composed mainly of medullated nerve-fibers which are derived originally from the spinal nerves.
2. The *great splanchnic nerve*, formed by the union of branches from the fifth to the tenth thoracic ganglia. It connects these ganglia with the semilunar ganglion.
3. The *small splanchnic nerve*, formed by the union of branches from the ninth and tenth thoracic ganglia. It connects these ganglia with the solar and renal plexuses.

Distribution of the Sympathetic Fibers.—It has been demonstrated by histologic and physiologic methods of investigation that the sympathetic non-medullated fibers which have their origin in the cells of the sympathetic ganglia, vertebral, pre-vertebral, and peripheral, are distributed ultimately and directly to but two structures: viz., *non-striated muscle* and *secretor epithelium*. Moreover, there is no evidence to warrant the assumption that these structures ever receive nerve impulses *directly* from the spinal or cranial nerves. All nerve impulses which influence their activities, either in the way of augmentation or inhibition, emanate *directly though not originally* from the sympathetic ganglion cells. Since non-striated muscles are found in the walls of blood-vessels, in the walls of hollow viscera,

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maxillary ganglion. 16, 17. Superior laryngeal nerve. 18. External laryngeal nerve. 19, 20. Recurrent laryngeal nerve. 21, 22, 23. Anterior branches of the upper four cervical nerves, sending filaments to the superior cervical sympathetic ganglion. 24. Anterior branches of the fifth and sixth cervical nerves, sending filaments to the middle cervical ganglion. 25, 26. Anterior branches of the seventh and eighth cervical and the first dorsal nerves, sending filaments to the inferior cervical ganglion. 27. Middle cervical ganglion. 28. Cord connecting the two ganglia. 29. Inferior cervical ganglion. 30, 31. Filaments connecting this with the middle ganglion. 32. Superior cardiac nerve. 33. Middle cardiac nerve. 34. Inferior cardiac nerve. 35, 35. Cardiac plexus. 36. Ganglion of the cardiac plexus. 37. Nerve following the right coronary artery. 38, 38. Intercostal nerves, with their two filaments of communication with the thoracic ganglia. 39, 40, 41. Great splanchnic nerve. 42. Lesser splanchnic nerve. 43, 43. Solar plexus. 44. Left pneumogastric. 45. Right pneumogastric. 46. Lower end of the phrenic nerve. 47. Section of the right bronchus. 48. Arch of the aorta. 49. Right auricle. 50. Right ventricle. 51, 52. Pulmonary artery. 53. Right half of the stomach. 54. Section of the diaphragm.—(*Sappey.*)

and around hair-follicles, and since secretor epithelium is found in all glands, there is every reason to believe that the ganglia in some

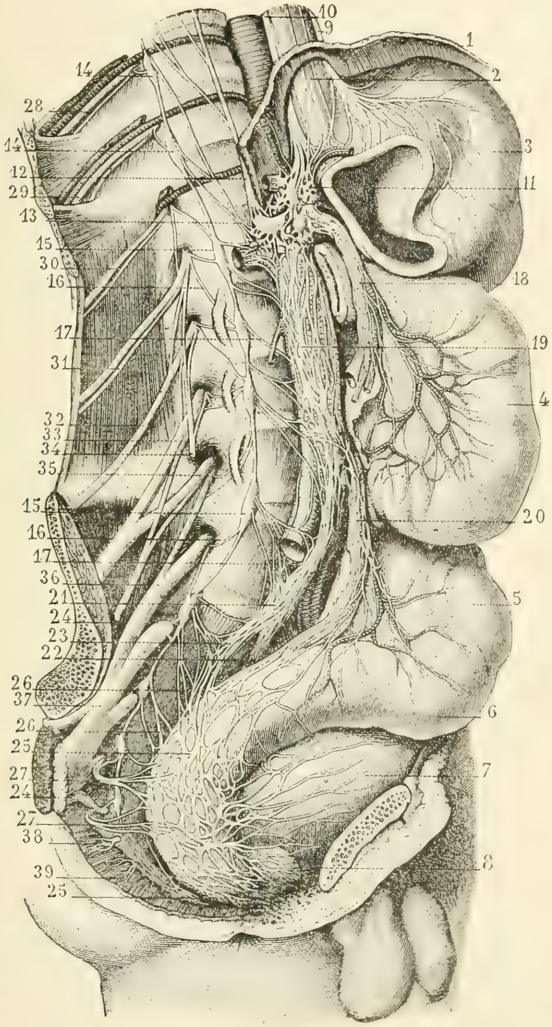

Fig. 286.—Lumbar and Sacral Portions of the Sympathetic. 1. Section of the diaphragm. 2. Lower end of the esophagus. 3. Left half of the stomach. 4. Small intestine. 5. Sigmoid flexure of the colon. 6. Rectum. 7. Bladder. 8. Prostate. 9. Lower end of the left pneumogastric. 10. Lower end of the right pneumogastric. 11. Solar plexus. 12. Lower end of the great splanchnic nerve. 13. Lower end of the lesser splanchnic nerve. 14, 14. Last two thoracic ganglia. 15, 15. The four lumbar ganglia. 16, 16, 17, 17. Branches from the lumbar ganglia. 18. Superior mesenteric plexus. 19, 21, 22, 23. Aortic lumbar plexus. 20. Inferior mesenteric plexus. 24, 24. Sacral portion of the sympathetic. 25, 25, 26, 26, 27, 27. Hypogastric plexus. 28, 29, 30. Tenth, eleventh, and twelfth dorsal nerves. 31, 32, 33, 34, 35, 36, 37, 38, 39. Lumbar and sacral nerves.—(*Sappey.*)

way are associated with vaso-augmentor and vaso-inhibitor, viscero-motor and viscero-inhibitor, pilo-motor and secretor phenomena.

The Anatomic Relations of the Sympathetic and Cerebro-spinal Systems.—The sympathetic ganglia are connected with the spinal nerves by two branches, one white, the other gray in color, and known respectively as the white and gray *rami communicantes.* These two rami differ somewhat in their topographic distribution. The white rami are found passing only from those spinal nerves included between the first thoracic and second or third lumbar and their corresponding ganglia. The gray rami, on the contrary, are found passing from the ganglia to each of the spinal nerves. In the cervical region, where the ganglia do not correspond in number with the cervical nerves, each ganglion gives off two or more gray rami. In man the superior cervical ganglion sends gray rami to the first four cervical nerves; the middle and inferior ganglia apparently send gray rami to the fifth and sixth, the seventh and eighth nerves respectively.

The **white rami** are composed of fine medullated nerve-fibers which arise from nerve-cells situated in the lateral portion of the gray matter in the thoracic and lumbar regions of the spinal cord. From this origin they pass forward into the ventral roots of the spinal nerves, in which they are contained until the spinal nerve formed by the union of the ventral and dorsal roots divides into its anterior and posterior divisions. At this point the fine medullated nerve-fibers leave the common trunk and pass forward into the corresponding vertebral ganglion, around the cell-bodies of which some of the fibers at once arborize. Other fibers, however, pass through this ganglion and ascend or descend the cord for a variable distance, and arborize around the cells of more or less distant ganglia; others again pass forward into the pre-vertebral and even the peripheral ganglia before they finally terminate. The nerve-cells in the spinal cord are thus brought into relation with the ganglia of all three chains, though for each cell there is but one ganglion terminal, one cell station, between the spinal cord and the tissues. Though innervated by the spinal cord, these structures receive their nerve impulses, as previously stated, not directly but indirectly through the ganglion cells. The medullated nerve-fibers coming from the spinal cord are known as *pre-ganglionic fibers;* the non-medullated fibers, passing from the ganglia, as *post-ganglionic fibers.*

The **gray rami** are composed of non-medullated nerve-fibers, axons of the cells in the vertebral or lateral ganglia. After their emergence from the ganglia they take a backward direction and enter the spinal nerve-trunks, in company with which they pass to the periphery, to be finally distributed to structures in the skin: viz., non-striated muscles of blood-vessels, non-striated muscles of the hair-follicles and epithelium of glands. They may therefore be regarded as having vaso-motor, pilo-motor, and secretor functions.

Afferent Sympathetic Fibers.—With the foregoing groups of efferent fibers, the sympathetic nerves, in the thoracic and lumbar regions more especially, contain a number of afferent fibers which when stimulated give rise to sensations of pain or to reflex phenomena. The routes by which these afferent fibers reach the spinal cord lead, on the one hand, into and through the gray rami to the ganglia on the posterior roots, where they have their cells of origin; and, on the other hand, into and through the white rami. The number of afferent fibers in any trunk in comparison with the efferent is quite small.

FUNCTIONS OF THE SYMPATHETIC SYSTEM.

The view according to which the sympathetic system is to be regarded as an independent apparatus endowed with functions of its own and in nowise directly dependent for its activities on the spinal cord, is at the present time discarded. Peripheral structures cease to exhibit their characteristic functions after division of the spinal nerves in connection with their related ganglia. This does not exclude the possibility of the sympathetic cell-body, in virtue of the interchanges between it and the blood and lymph by which it is surrounded, maintaining its own nutrition and exerting a favorable influence over the nutrition of the peripheral tissues to which its efferent branches are distributed.

The nerve-tissue in its entirety may be regarded as a single system which may be functionally divided into a nerve system of animal and a nerve system of vegetative life, according as the nerve energies originating in and emanating from the central nervous system are transmitted directly to the skeletal muscles or indirectly, through the intervention of a sympathetic neuron, to visceral muscles and glands. In the former system but one neuron, the spino-peripheric, connects the spinal cord proper with the muscle; in the latter system there are two, the spino-ganglionic and the ganglio-peripheric.

From the distribution of the post-ganglionic fibers it may be inferred that the activities of the vascular and visceral muscles, either in the way of augmentation or inhibition, the activities of the muscles of the hair-follicles, and of the epithelium of glands, are called forth by the ganglia in consequence of the arrival of nerve impulses coming from the spinal cord through the pre-ganglionic fibers. Experimental observations show this to be true. The extent to which these different modes of activity manifest themselves in one or more regions of the body will depend to some extent on the portion of the sympathetic system subjected to experimental procedures.

The Functions of the Cervical Portion.—If the sympathetic cord central to the superior cervical ganglion be stimulated with the induced electric current, among the resulting phenomena there will be observed dilatation of the pupil, retraction of the nictitating membrane in animals possessing it, contraction of the blood-vessels of the skin and mucous membrane in different parts of the head and face, contraction of the blood-vessels of the salivary glands, *increase* of secretion from the submaxillary gland, the perspiratory and mucous glands, erection of hairs in different localities of the head and neck, and in the dog *dilatation* of the blood-vessels of the lips, gums, and hard palate. If the cervical cord be divided, opposite effects will be observed: viz., contraction of the pupil, dilatation and passive congestion of the blood-vessels, a rise in temperature, and a loss of the power of erecting hairs. Stimulation of the peripheral end causes a disappearance of the latter and a reappearance of the former phenomena. These facts indicate that the cervical portion is efferent in function. The fibers composing it are medullated nerve-fibers derived from the thoracic or dorsal nerves from the first to the fourth. From the several sources the fibers pass *via* the white rami into the vertebral chain, and thence without interruption to the superior cervical ganglion, in and around the cells of which their end-tufts arborize in their characteristic manner.

That the superior cervical ganglion is the cell station between the spinal cord and the peripheral organs is shown by the fact discovered and applied by Langley that the intravenous injection of nicotin or the local application of it to the ganglion itself, impairs the conductivity of the terminals of pre-ganglionic fibers, after which their stimulation has no effect on the ganglion cells, though the latter retain their activity, as shown on direct stimulation. Of the nerve-centers in the spinal cord which through pre-ganglionic fibers influence peripheral structures, some appear to be in a state of constant activity: *e. g.*, the vaso-constrictor centers and the pupillo-dilatator centers. In how far this action is automatic or autochthonic, or reflex, is uncertain.

The Functions of the Thoracic Portion.—The phenomena which follow stimulation of this portion of the sympathetic system resemble in a general way those observed in the head when the cervical portion is stimulated. The situation of the resulting phenomena will vary in accordance with the part the subject of the experiment. For an understanding of the results of experiment the origin and distribution of the following nerve-branches must be kept in view:

(*a*) The *cardiac nerves* which take their origin in part in cells in the first thoracic or stellate ganglion, and in part in cells in the inferior cervical ganglion. From this origin they pass downward and forward and reach the heart by way of the cardiac plexus. Stimulation of these nerves gives rise to an increased frequency and an augmentation in the force of the heart-beat. The pre-ganglionic fibers by which these cells are excited to activity emerge from the cord by the first and second thoracic nerves.

(*b*) *The splanchnic nerves* the roots of which emerge from the fourth to the tenth or eleventh thoracic ganglia. The fibers composing these nerves are for the most part pre-ganglionic and derived from the corresponding spinal nerves. The cell stations of the splanchnic fibers are in the semilunar, superior mesenteric, and renal ganglia. From these ganglia non-medullated post-ganglionic fibers pass peripherally to the walls of the intestines, the blood-vessels of the intestines, liver, kidneys, spleen, etc. *Stimulation* of the great splanchnic produces inhibition of the intestinal movements, a marked primary contraction of the intestinal movements, a marked primary contraction of the intestinal blood-vessels and other viscera, followed by dilatation, coincidently with which there is a primary rise succeeded by a fall of blood-pressure throughout the body. *Division* of the nerve is followed by dilatation of the intestinal vessels and a fall of blood-pressure. *Stimulation* of the central end of the divided nerve excites the activity of the general vaso-motor center, as shown by the rise of the general blood-pressure. Stimulation of the smaller splanchnics gives rise to a slight primary contraction of the blood-vessels, soon followed by a marked dilatation. These facts indicate that the splanchnic nerves contain visceral nerves which inhibit intestinal movements, vaso-motor fibers both augmentor and inhibitor. The presence of secretor nerves for the intestinal glands is disputed.

(*c*) The *cutaneous nerves* for the *trunk* leave the lateral ganglia by the gray rami, enter the thoracic spinal nerves, and pass in company with them to their terminations, to be ultimately distributed to the walls of the blood-vessels, the arrectores pilorum muscles, and the sweat-glands. The pre-ganglionic fibers come from the spinal nerves by the white rami. Their functions are vaso-motor, pilo-motor, and secretor. The cutaneous nerves for the *fore-limbs* have their origin from cells in the stellate ganglion (first dorsal). After a short upward course they enter the trunks of the nerves composing the brachial plexus. The pre-ganglionic fibers come from the white rami of the fourth to the ninth thoracic nerves. After entering the lateral chain they take an upward direction and arborize around the cells of the stellate ganglion. The cutaneous nerves for the *hind-limbs* are derived from the lower lumbar and the upper sacral ganglia. They also enter the spinal nerves by the gray rami and pass to the blood-vessels and glands of the skin. The pre-ganglionic fibers come from the twelfth thoracic to the third lumbar nerves. In both the brachial and sciatic nerves vaso-motor fibers (constrictors and dilatators) and secretor nerves are present, as shown by experimental methods (see page 374).

The Functions of the Lumbo-sacral Portion.—From the ganglia of the lumbar and sacral regions gray rami enter the lumbar and sacral nerves and accompany them to their distribution. In the lumbar region the vertebral chain contains a number of pre-ganglionic fibers which have descended from the thoracic region as well as fibers which have come into the chain by the white rami from the lumbar nerves themselves. Many of these fibers pass to the inferior mesenteric ganglion, in which they find their cell station. Fibers from the sacral cord pass into the hypogastric plexus. The course and distribution of the individual nerves is complicated and involved. In a general way it may be said that these two regions of the lateral chain send viscero-motor and viscero-inhibitor, vaso-constrictor and dilator nerves to the pelvic viscera and to the external organs of generation. Their function therefore is to regulate the activities of the viscera as well as the blood-supply in accordance with functional needs.

The Functions of the Cephalic Ganglia.—The ganglia situated in the head are usually described in connection with and as constituent parts of the cranial nerve system. They, however, bear the same relation to the cranial nerves that the ganglia of the trunk bear to the spinal nerves. They consist of ganglion cells *from* which post-ganglionic fibers pass to glands, blood-vessels, and non-striated muscles, and *to* which pre-ganglionic fibers pass from the cranial nerves. Motor and sensor nerves pass through one or more ganglia, though they have no anatomic connection with them. In their structure, distribution, and functions they closely resemble the collateral ganglia of the abdominal sympathetic:

1. The *ciliary* or *ophthalmic ganglion* is situated in the orbital cavity posterior to the eyeball. It is small in size, gray in color, and consists of a connective-tissue stroma containing nerve-cells. From these cells post-ganglionic fibers emerge which, after a short course forward, penetrate the eyeball and terminate in the circular fibers of the iris and the ciliary muscle. Pre-ganglionic fibers of small size, and similar in their anatomic features to the fibers of the white rami of the spinal nerves, leave the motor oculi by a short root from the inferior division and arborize around the ganglionic cells. *Stimulation* of the pre-ganglionic fibers gives rise to contraction of the circular fibers of the iris, with a diminution in the size of the pupil, and contraction of the ciliary muscle with accommodation of the eye for near vision. *Division* of these fibers is followed by the opposite results. Post-ganglionic fibers from the superior cervical ganglion which come through the cavernous plexus pass through the ciliary ganglion to the blood-vessels of the iris and retina which are vaso-constrictor in function. Sensor fibers from the peripheral division of the fifth nerve pass to the cornea and endow it with sensibility.
2. The *spheno-palatine ganglion* is situated in the spheno-maxillary fossa. Its nerve-cells send non-medullated post-ganglionic fibers to the blood-vessels and glands of the mucous membrane of the nasal and oral regions. Stimulation of the ganglion gives rise to dilatation of the blood-vessels and increase of secretion in this entire region. The pre-ganglionic fibers are derived from the

seventh or facial nerve by way of the great petrosal. Sensor fibers from the superior maxillary division of the fifth nerve pass through the ganglion to the same regions.

3. The *otic ganglion* is situated just below the foramen ovale and internal to the third division of the fifth nerve. The post-ganglionic fibers pass to the parotid gland by way of the auriculotemporal division of the fifth nerve, and to the blood-vessels of the mucous membrane of the lower lip, cheek, and gums. The preganglionic fibers are derived from the efferent fibers in the glossopharyngeal or ninth nerve, by way of Jacobson's nerve and the small petrosal. *Stimulation* of these nerves in any part of their course gives rise to vascular dilatation and increase of secretion in the region of their distribution. Motor fibers from the small or motor root of the fifth nerve pass through this ganglion to the tensor tympani muscle.
4. The *submaxillary* and *sublingual ganglia* are situated close to the corresponding glands. Their post-ganglionic fibers pass to the blood-vessels and gland-cells. The pre-ganglionic fibers are derived from the seventh or facial nerve through the chorda tympani branch. Stimulation of the chorda or of the ganglia themselves gives rise to marked dilatation of the blood-vessels and an increased flow of saliva. It therefore contains vasodilatator and secretor fibers for these glands. Vaso-constrictor and a few secretor nerves, it will be recalled, come to these glands from the superior cervical ganglion.

Peripheral Ganglia.—Among the peripheral ganglia may be mentioned those in the heart and those in the intestinal walls. The pre-ganglionic fibers are contained in the trunk of the vagus nerve. Stimulation of the peripheral end of the divided vagus gives rise to inhibition of the heart, contraction of the walls of the stomach and intestines, secretion from the gastric and perhaps the pancreatic gland.

CHAPTER XXV.

PHONATION; ARTICULATE SPEECH.

Phonation, the emission of vocal sounds, is accomplished by the vibration of two elastic membranes which cross the lumen of the larynx antero-posteriorly and which are thrown into vibration by a blast of air from the lungs.

Articulate speech is a modification of the vocal sounds or the voice produced by the teeth and the muscles of the lips and tongue and is employed for the expression of ideas.

The larynx, the organ of the voice, is situated in the forepart of the neck, occupying the space between the hyoid bone and the upper extremity of the trachea. In this situation it communicates with the cavity of the pharynx above and the cavity of the trachea below. From its anatomic relations and its internal structure—the interpolation of the elastic membranes—the larynx subserves the two widely different yet related functions, respiration and phonation.

THE ANATOMY OF THE LARYNX.

The larynx consists primarily of a series of cartilages united one with another in such a manner as to form a more or less rigid framework, yet possessing at its different joints, a certain amount of motion; and secondarily, of muscles and nerves which conjointly impart to the cartilages the degree of movement necessary to the performance of the laryngeal functions. It is covered externally by fibrous tissue and lined throughout by mucous membrane continuous with that lining the pharynx and trachea.

The larynx presents a superior or pharyngeal and an inferior or tracheal opening. The pharyngeal opening is triangular in shape, the base being directed forward, the apex backward. The plane of this opening in the living subject is almost vertical. The tracheal opening is circular in shape and corresponds in size with the upper ring of the trachea. Viewed from above, the general cavity of the larynx is seen to be partially subdivided by two membranous bands—the *vocal bands* or cords—which run from before backward in a horizontal plane. The space between the bands, the *glottis*, varies in size and shape from moment to moment in accordance with respiratory and phonatory necessities. The average width of the glottis, at its widest part, during quiet respiration is about 13.5 mm. in men and 11.5 mm. in women. With the advent of phonation the vocal membranes are at once approximated, and to such an extent that the glottic opening is reduced to a mere slit. It is then spoken of as the *rima glottidis*, or chink of the glottis.

The space above the vocal bands, the supra-glottic or supra-rimal space, is triangular in shape and extends from the pharyngeal opening to the plane of the vocal bands. The mucous membrane lining the walls of this space, presents on either side, just above the vocal bands, a crescentic fold which runs from before backward, and is known as the false vocal band or cord. Between the true and false bands there is a cavity or space prolonged upward and outward for some distance, forming what is known as the ventricle of the larynx. The space below the vocal bands, the infra-glottic or infra-rimal space, is narrow above and elongated from before backward, but wide and circular below, corresponding to the lumen of the trachea. (Fig. 287.)

The Laryngeal Cartilages, Articulations, and Ligaments.—The cartilages which compose the framework of the larynx are nine in number, three of which are single: viz., the cricoid, the thyroid, and the epiglottis, while six occur in pairs: viz., the arytenoids, the cornicula laryngis, and the cuneiform. (Figs. 288 and 289.)

The *cricoid* cartilage is the foundation cartilage, and affords support to the remaining cartilages and the structures attached to them. In shape it resembles a signet-ring, the broad quadrate portion of which is directed backward, while the narrow circular portion is directed forward. It rests upon the upper ring of the trachea, to which it is firmly attached by fibrous tissue. The posterior upper border of the quadrate portion presents on either side an oval convex facet for articulation with the arytenoid cartilage. The long axis of this facet is directed downward, outward, and forward.

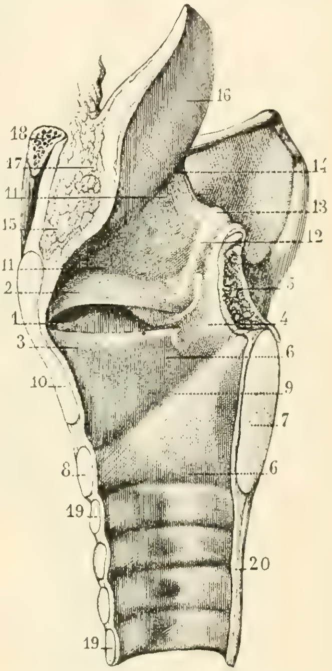

FIG. 287.—LONGITUDINAL SECTION OF THE HUMAN LARYNX, SHOWING THE VOCAL BANDS. 1. Ventricle of the larynx. 2. Superior vocal cord 3. Inferior vocal cord. 4. Arytenoid cartilage. 5. Section of the arytenoid muscle. 6, 6. Inferior portion of the cavity of the larynx. 7. Section of the posterior portion of the cricoid cartilage. 8. Section of the anterior portion of the cricoid cartilage. 9. Superior border of the cricoid cartilage. 10. Section of the thyroid cartilage. 11, 11. Superior portion of the cavity of the larynx. 12, 13. Arytenoid gland. 14, 16. Epiglottis. 15, 17. Adipose tissue. 18. Section of the hyoid bone. 19, 19, 20. Trachea.—(*Sappey.*)

The *thyroid*, the largest of the laryngeal cartilages, is composed of two flat quadrilateral plates, united anteriorly, at an angle of about 90 degrees. Each plate is directed backward and outward and terminates in a free border, which is prolonged upward and downward for some distance, terminating in two processes, the superior and inferior cornua. The upper border of the thyroid is deeply notched in front. The inferior border overlaps laterally the cricoid.

The *epiglottis* is a leaf-shaped piece of cartilage attached to the thyroid at the median notch. It is firmly united by membranes and ligaments to the thyroid and arytenoid cartilages and to the base of the tongue.

The *arytenoid cartilages* are two in number and symmetric in shape. Each cartilage is a triangular pyramid, the apex of which is recurved, and directed backward and inward. The base presents three angles—an anterior, an external, and an internal. The anterior angle is long and pointed and projects forward in a horizontal plane. It serves for the attachment of the vocal membranes and is therefore termed the *vocal process*. The external angle is short, rounded, and prominent, and serves for the attachment of muscles. The internal angle affords a point of insertion for a ligament. The inferior surface of the arytenoid is concave for articulation with the convex surface of the cricoid facet. Its long axis, however, is directed from before

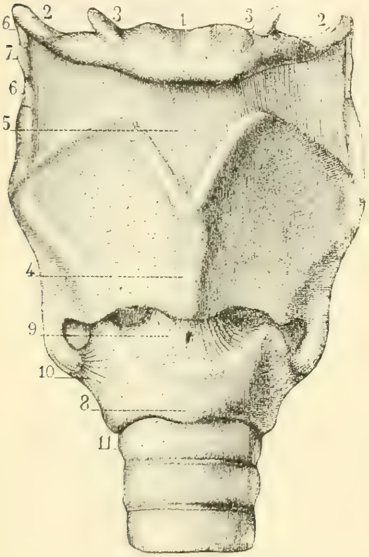

FIG. 288.—LARYNGEAL CARTILAGES AND LIGAMENTS, ANTERIOR SURFACE. 1. Hyoid bone. 2, 2, 3, 3. Greater and lesser cornua. 4. *Thyroid cartilage.* 5. *Thyro-hyoid membrane.* 6. Thyro-hyoid ligaments. 7. Cartilaginous nodule. 8. *Cricoid cartilage.* 9. The *crico-thyroid membrane.* 10. The crico-thyroid ligaments. 11. Trachea.—(*Sappey.*)

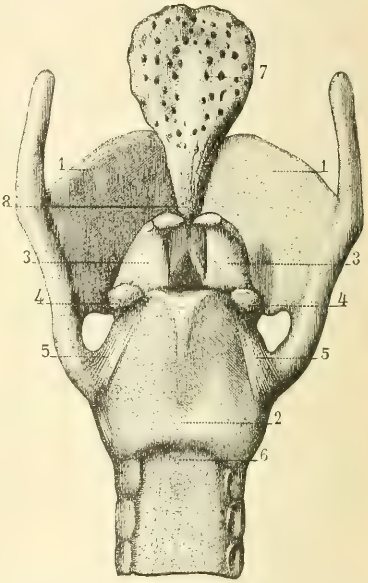

FIG. 289.—LARYNGEAL CARTILAGES AND LIGAMENTS, POSTERIOR SURFACE. 1, 1. *Thyroid cartilage.* 2. *Cricoid cartilage.* 3, 3. *Arytenoid cartilages.* 4, 4. *Crico-arytenoid articulations.* 5, 5. *Crico-thyroid articulations.* 6. Union of the cricoid cartilage and of the trachea. 7. Epiglottis. 8. Ligament uniting it to the reentering angle of the thyroid cartilage.—(*Sappey.*)

backward and almost at right angles to the long axis of the cricoid facet.

The *cornicula laryngis* and the *cuneiform* cartilages are small nodules of yellow elastic cartilage embedded in a fold of membrane which unites the arytenoid and the epiglottis. They are fragments of a ring of cartilage which in some animals—*e. g.*, anteater—extends between these two cartilages.

The *crico-thyroid articulation* is formed by the opposition of the tip of the inferior cornu of the thyroid cartilage and an articular facet on the side of the cricoid. The joint is provided with a synovial membrane and enclosed by a capsular ligament. The movements permitted at this joint take place around a horizontal axis and consist of an upward and downward movement of both the thyroid and cricoid, combined with a sliding movement of the latter upward and backward.

The *crico-arytenoid articulation* is formed by the apposition of the articulating surfaces of the cricoid and arytenoid cartilages. This joint is provided with a synovial membrane and enclosed by a loose capsular ligament which would permit of an extensive sliding of the arytenoid cartilage downward and outward were it not prevented by the posterior crico-arytenoid ligament, which is attached, on the one hand, to the cricoid, and, on the other, to the inner angle of the arytenoid. The movements permitted at this joint are: (1) Rotation of the arytenoid around a vertical axis which lies close to its inner surface. (2) A sliding motion inward and forward with inward rotation of the vocal process, or a sliding motion outward and backward with outward rotation of the vocal process. In either case the process describes an arc of a circle. (3) A sliding movement towards the median line in consequence of which the inner surfaces of the arytenoids are brought almost in contact.

The *crico-thyroid membrane* is composed mainly of elastic tissue. It may be divided into a mesial and two lateral portions. The mesial portion is well developed, triangular in shape, and unites the contiguous borders of the cricoid and thyroid cartilages. The lateral portion is attached below to the superior border of the cricoid. From this attachment it passes upward and inward under cover of the thyroid. As it ascends it elongates and becomes thinner, and is finally attached anteriorly to the thyroid near the median line, and posteriorly to the vocal process of the arytenoid, thus constituting the *inferior thyro-arytenoid* ligament. It is covered internally by mucous membrane and externally by the internal thyro-arytenoid muscle. The free edge of this ligament forms the basis of the true vocal band. A superior thyro-arytenoid ligament forms the basis of the false vocal band.

The *thyro-hyoid* membrane, composed of elastic tissue, unites the superior border of the thyroid to the hyoid bone.

The *mucous membrane* lining the larynx is thin and pale. As it passes downward it is reflected over the superior thyro-arytenoid ligament, and assists in the formation of the false vocal band; it then passes into and lines the ventricle, after which it is reflected inward over the superior border of the thyro-arytenoid muscle and ligament, and assists in the formation of the true vocal band; it then returns upon itself and passes downward over the lateral portion of the crico-thyroid membrane into the trachea.

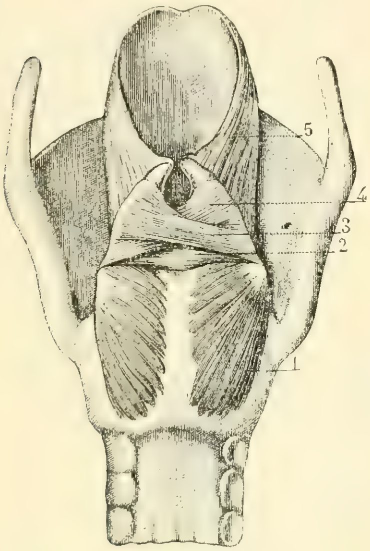

Fig. 290.—Posterior View of the Muscles of the Larynx. 1. Posterior crico-arytenoid muscle. 2, 3, 4. Different fasciculi of the arytenoid muscle. 5. Aryteno-epiglottidean muscle.—(*Sappey.*)

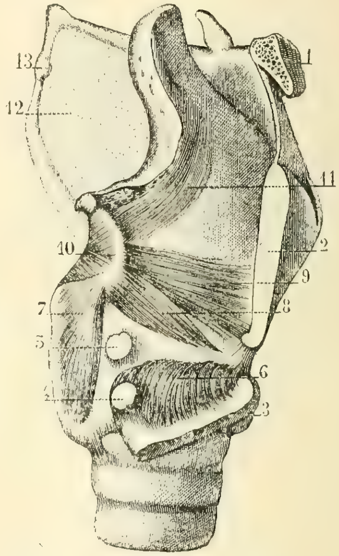

Fig. 291.—Lateral View of the Muscles of the Larynx. 1. Body of the hyoid bone. 2. Vertical section of the thyroid cartilage. 3. Horizontal section of the thyroid cartilage turned downward to show the deep attachment of the crico-thyroid muscle. 4. Facet of articulation of the small cornu of the thyroid cartilage with the cricoid cartilage. 5. Facet on the cricoid cartilage. 6. Superior attachment of the crico-thyroid muscle. 7. Posterior crico-arytenoid muscle. 8, 10. Arytenoid muscle. 9. Thyro-arytenoid muscle. 11. Aryteno-epiglottidean muscle. 12. Middle thyro-hyoid ligament. 13. Lateral thyro-hyoid ligament.—(*Sappey.*)

The thin, free, reduplicated edge of the mucous membrane constitutes the true vocal band. The surface of the mucous membrane is covered by ciliated epithelium except in the immediate neighborhood of the vocal bands.

The *vocal bands* are attached anteriorly to the thyroid cartilage near the receding angle and posteriorly to the vocal processes of the arytenoid cartilages. They vary in length in the male from 20 to 25 mm. and in the female from 15 to 20 mm.

The Muscles of the Larynx.—The muscles which have a direct action on the cartilages of the larynx and determine the position of the vocal bands both for respiratory and phonatory purposes, and which regulate their tension as well, are nine in number and take their names from their points of origin and insertion: viz., two posterior crico-arytenoids, two lateral crico-arytenoids, two thyro-arytenoids, one arytenoid, and two crico-thyroids (Figs. 290 and 291).

The *posterior crico-arytenoid* muscle lies on the posterior surface of the quadrate plate of the cricoid cartilage, on either side of the median line, from which it takes its origin. The fibers of the muscle pass upward and outward and in their course converge to be inserted into the external angle of the arytenoid cartilage. The superior and more horizontally directed fibers rotate the arytenoid around its vertical axis; the inferior and obliquely directed fibers draw the cartilage downward and inward. As a result of the action of the muscle in its entirety, the vocal process is turned upward and outward, and as the vocal band is carried with it the glottis is widened, a condition necessary to the free entrance of air into the lungs (Fig 292). Since the contraction of the crico-arytenoid has this result, it is generally spoken of as the *abductor* or *respiratory* muscle.

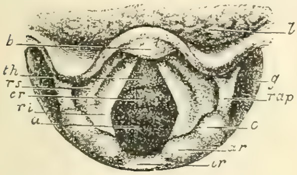

FIG. 292.—GLOTTIS WIDELY OPENED FROM SIMULTANEOUS CONTRACTION OF BOTH CRICO-ARYTENOID MUSCLES. *b*. Epiglottis. *rs*. False vocal band. *ri*. True vocal band. *ar*. Arytenoid cartilages. *a*. Space between the arytenoids. *c*. Cuneiform cartilages. *ir*. Interarytenoid fold. *rap*. Aryepiglottic fold. *cr*. Cartilage rings.—(*Mandl.*)

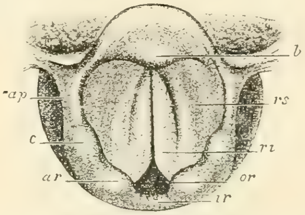

FIG. 293.—POSITION OF THE VOCAL BANDS DUE TO THE SIMULTANEOUS CONTRACTION OF BOTH LATERAL CRICO-ARYTENOID MUSCLES AND BOTH THYRO-ARYTENOID MUSCLES. *b*. Epiglottis. *rs*. False vocal band. *ri*. True vocal band. *or*. Space between the arytenoid cartilages, the *glottis respiratoria*. *ar*. Arytenoid cartilages. *c*. Cuneiform cartilages. *rap*. Aryepiglottic fold. *ir*. Interarytenoid fold.—(*Mandl.*)

The *lateral crico-arytenoid* muscle arises from the side of the cricoid cartilage. From this point its fibers are directed upward and backward to be inserted into the external process of the arytenoid. Its action is to draw the arytenoid cartilage forward and inward, thus approximating and relaxing the vocal band.

The *thyro-arytenoid* muscle arises from the inferior two-thirds of the inner surface of the thyroid cartilage just external to the median line. From this origin the fibers pass backward and outward, to be inserted into the anterior surface and external angle of the arytenoid cartilage. The inner portion of the muscle lies close to and supports, if it does not constitute a part of, the vocal band. The action of the thyro-arytenoid muscle in conjunction with the lateral crico-arytenoid is to rotate the arytenoid cartilage around the vertical axis and to draw the vocal process forward and inward, thus carrying the vocal cord toward the median line. When the muscles of the two sides simultaneously contract, the vocal bands are closely approximated and the space between them, the *rima vocalis*, reduced to a mere slit, one of the conditions essential to phonation (Fig. 293).

The *arytenoid* muscle consists (1) of transversely arranged fibers which arise from and are inserted into the outer surface of the opposite arytenoid cartilages, and (2) of obliquely directed fibers which arise from the outer angle of one arytenoid to be inserted into the apex of the other. In their course they decussate in the median line. The action of this muscle is to approximate the arytenoid cartilages and thus obliterate that portion of the glottis between the vocal processes, the *rima respiratoria*, and so direct the expiratory blast of air toward and through the rima vocalis.

The collective actions of the three foregoing muscles is to close or constrict the glottis, and for this reason they are spoken of as the *adductor* or *phonatory* muscles.

The *crico-thyroid* muscle arises from the side and front of the cricoid cartilage and is inserted above into the lower border of the thyroid cartilage. The action of this muscle is to draw up the anterior part of the cricoid cartilage toward the thyroid, which remains stationary, and to swing the quadrate plate of the cricoid and the arytenoid cartilages downward and backward. This movement has the result of tensing the vocal bands. The cricoid is at the same time drawn backward by the action of the more longitudinally disposed fibers.

Nerves of the Larynx.—The nerves which innervate the muscles of the larynx and endow the mucous membrane with sensibility are derived from the vagus trunk. The superior laryngeal is for the most part sensor and distributed to the mucous membrane, though it contains motor fibers for the crico-thyroid muscle. The inferior laryngeal is purely motor and is distributed to all the muscles with the exception of the crico-thyroid.

THE MECHANISM OF PHONATION.

Phonation, the production of vocal sounds in the larynx, is the result of the vibration of the vocal bands caused by an expiratory blast of air from the lungs. That a sound may arise it is essential that the glottis be approximately closed and the vocal bands be made more or less tense.

The closure of the glottis—the approximation of the vocal processes and the vocal bands—is accomplished, it will be recalled, by the contraction of the lateral crico-arytenoid, the arytenoid, and the thyro-arytenoid muscles. The increase in tension is accomplished by the contraction of the crico-thyroid and the thyro-arytenoid muscles, the former by the backward displacement of the cricoid and arytenoid cartilages, the latter by converting the natural concave edge of the vocal band to a straight line. The lengthening and tensing of the vocal bands by the crico-thyroid muscle is regarded by some investigators as a coarse means, the approximation of the free edges by the thyro-arytenoid, as a finer means, of adjustment for the production of slight changes in the pitch of sounds. The extent to which the glottis is closed and the membranes tensed will depend, however, on the pitch of the sound to be emitted. The appearance presented by the glottis just previous to the emission of a note of medium pitch, as determined by laryngologic examination, is shown in Fig. 294. When the foregoing conditions in the glottis are realized, the air stored or collected in the lungs is forced by the contraction of the expiratory muscles, through the narrow space between the bands. As a result of the resistance offered by this narrow outlet and the force of the expiratory muscles the air within the lungs and trachea is subjected to pressure, and as soon as the pressure attains a certain level the vocal bands are thrown into vibrations, which in turn impart to the column of air in the upper air-passages a corresponding series of vibrations by which the laryngeal vibrations are reinforced. The degree of pressure to which the air in the lungs and trachea is subjected was determined by Latour to vary from 160 mm. of water for sounds of moderate, to 940 mm. of water for sounds of highest intensity. With the escape of the air or the separation of the vocal bands the vibration ceases and the sound dies away.

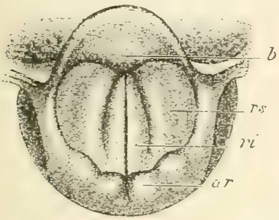

FIG. 294.—POSITION OF THE VOCAL BANDS PREVIOUS TO THE EMISSION OF A SOUND. *b.* Epiglottis. *rs.* False vocal band. *ri.* True vocal band. *ar.* Arytenoid cartilages.—(*Mandl.*)

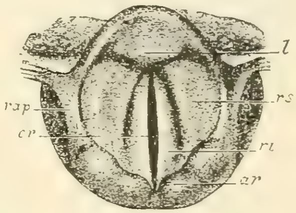

FIG. 295.—POSITION OF THE VOCAL BANDS IN THE PRODUCTION OF NOTES OF LOW PITCH. *l.* Epiglottis. *or.* Glottis. *ns.* False vocal cord. *ni.* True vocal cord. *ar.* Arytenoid cartilages.—(*Mandl.*)

The Characteristics of Vocal Sounds.—In common with the sounds produced by all other music instruments, all vocal sounds are characterized by intensity, pitch and quality, tone or color.

The *intensity* or loudness of a sound depends on the extent or amplitude of the up-and-down vibration or the extent of the excursion of the vocal band on either side of the position of equilibrium or rest; and this in turn depends on the force with which the blast of air strikes the band. The more forceful the blast of air, the larger, other things being equal, will be the primary vibrations of the bands, and hence the secondary vibrations of the air in the upper air-passages.

The *pitch* of the voice depends on the number of vibrations in a unit of time, a second. This will be conditioned by the length of the bands in vibration or the length and width of the aperture through which the air passes and the degree of tension to which the bands are subjected. In the emission of sounds of highest pitch the tension of the vocal bands and the narrowing of the glottis attain their maximum. In the emission of sounds of lowest pitch the reverse conditions obtain. In passing from the lowest to the highest pitched sounds in the range of the voice peculiar to any one individual, there is a progressive increase in both the tension of the vocal bands and the narrowing of the glottic aperture. In the production of low-pitched notes of men, those due to vibrations lying between 80 and 240 per second, the tension is regulated by the crico-thyroid muscle; the aperture of the glottis during this time being elliptic in shape and relatively wide (Fig. 295). In the production of notes due to vibrations lying between 240 and 512 vibrations per second, the anterior fibers of the cricothyroid muscle relax and the thyroarytenoid muscle comes into play; by its action the vocal bands are more closely approximated and the vocal aperture reduced to a linear slit. In the high-pitched notes emitted by soprano singers the vocal bands are so closely applied to each other that only a very small portion in front, bounding a small oval aperture, is capable of vibrating (Fig. 296). The difference in the pitch of the voice in men and women is due largely to the greater size and development of the vocal bands in the former than in the latter.

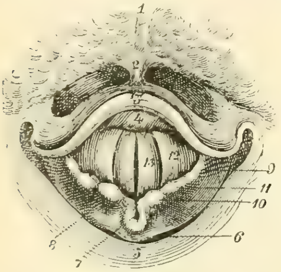

FIG. 296.—GLOTTIS SEEN WITH THE LARYNGOSCOPE DURING THE EMISSION OF HIGH-PITCHED SOUNDS. 1, 2. Base of the tongue. 3, 4. Epiglottis. 5, 6. Pharynx. 7. Arytenoid cartilages. 8. Opening between the true vocal cords. 9. Aryteno-epiglottidean folds. 10. Cartilage of Santorini. 11. Cuneiform cartilage. 12. Superior vocal cords. 13. Inferior vocal cords.—(*Le Bon.*)

The *quality* of the voice, the timbre or color, depends on the *form* combined with the intensity and pitch of the vibration. As with sounds produced by music instruments, the primary or fundamental vibration of the vocal band is complicated by the superposition of secondary or partial vibrations (overtones). The form of the vibration will therefore be a resultant of the blending of a number of different vibrations. The quality of the sound produced in the larynx is, however, modified by the resonance of the mouth and nasal cavities; certain of the overtones being reinforced by changes in the shape of the mouth cavity more especially, thus giving to the voice a somewhat different quality.

The Varieties of Voice.—The region of the music scale, comprising all vibrations between 32 and 2048 per second, with which laryngeal sounds are in accord will vary in the two sexes and in different individuals of the same sex. It is customary to classify voices, especially those of singers, into bass, baritone, tenor, contralto, mezzo-soprano, and soprano, in accordance with the regions of the music scale with which they correspond. Thus the succession of notes characteristic of the bass voice vary in pitch from F, fa′, to C′, do$_3$, or from 87 to 256 vibrations per second; those of the baritone from A, la, to F′, fa$_3$, or from 106 to 341 vibrations per second; those of the tenor from C, do$_2$, to a′, la$_3$, or from 128 to 435 vibrations per second; those of the contralto from e, mi$_2$, to C″, do$_4$, or from 160 to 512 vibrations per second; those of the mezzo-soprano from g, sol$_2$, to e″, mi$_4$, or from 192 to 640 vibrations per second; those of the soprano from b, si$_2$, to g″, sol$_4$, or from 240 to 768 vibrations per second. The range of the voice is thus seen to embrace from one and three-quarters to two octaves. Some few individual singers have far exceeded this range, but they are exceptional.

Speech is the expression of ideas by means of articulate sounds. These sounds may be divided into vowel and consonant sounds.

The vowel sounds, *a*, *e*, *i*, *o*, *u*, are laryngeal sounds modified by the superposition and reinforcement of certain overtones developed in the mouth and pharynx by changes in their shapes. The number of vibrations underlying the production of each vowel sound is a matter of dispute. According to König, the sound of a is the result of 940 vibrations; of e, 1880 vibrations; of i, 3760 vibrations; of o, 470 vibrations; of ou, 235 vibrations.

Consonant sounds are produced by the more or less complete interruption of the vowel sounds during their passage through the organs of speech. These may be divided into:

1. Labials, *p*, *b*, *m*.
2. Labio-dentals, *f*, *v*.
3. Linguo-dentals, *s*, *z*.
4. Anterior linguo-palatals, *t*, *d*, *l*, *n*.
5. Posterior linguo-palatals, *k*, *g*, *h*, *y*, *r*.

The names of these different groups of consonants indicate the region of the mouth in which they are produced and the means by which the air blast is interrupted.

THE NERVE MECHANISM OF THE LARYNX.

The nerve mechanism by which the musculature of the larynx is excited to action and coördinated so as to subserve both respiration and phonation involves the fibers contained in the superior and inferior laryngeal nerves (both branches of the vagus) and their related nerve-centers in the central nerve system.

For respiratory purposes it is essential that the lumen of the glottis shall be sufficiently large to permit the entrance and exit of air without hindrance. Laryngoscopic examination of the larynx in the human being shows that during *quiet* respiration the vocal bands are widely separated and almost stationary, moving but slightly during either inspiration or expiration. At this time, according to the investigations of Semon, the area of the glottis is approximately 160 sq. mm., somewhat less than the area of either the supraglottic or infraglottic regions, which is about 200 sq. mm. This condition of the glottis is maintained by the steady continuous contraction of the posterior crico-arytenoid muscles, the *abductors of the vocal bands.*

For phonatory purposes it is essential that the respiratory function be temporarily suspended and the vocal bands closely approximated. This is accomplished by the contraction of the remaining muscles of the larynx, with the exception of the crico-thyroid, which are collectively known as the *adductors of the vocal bands.* During phonation the adductor muscles overcome the activity of the abductors. With the cessation of phonation the abductors immediately restore the vocal bands to their former respiratory position.

The activities of these two antagonistic groups of muscles are under the control of the central nerve system. The only pathway for the excitatory nerve impulses is through the fibers of the inferior or recurrent laryngeal nerve. The relation of these nerve-fibers both centrally and peripherally, as well as their physiologic action, has been the subject of much experimentation. The results have not always been in accord, owing to the choice of animal, the use of anesthetics, strength of stimulus, etc.

As the outcome of many investigations it is believed that each muscle group is innervated by its own bundle of nerve-fibers, both of which are contained in the inferior laryngeal, though coming from two separate centers in the medulla oblongata. Russell succeeded in separating the fibers for the abductors from the fibers for the adductors in the inferior laryngeal, and in tracing them to their terminations. So completely was this done that it became possible to produce at will, through stimulation, either abduction or adduction, without contraction of the muscle of opposite function.

The *laryngeal respiratory center* was located by Semon and Horsley, in the cat, in the upper part of the floor of the fourth ventricle. Stimulation of this area during etherization was followed by abduction of the vocal bands. The efferent fibers of this center are believed by some investigators to leave the central nerve system in the spinal accessory nerve, by others in the lower roots of the vagus.

From the continuous activity of the abductor muscle, and the stationary position of the vocal bands, it is probable that the medullary center is in a state of continuous activity or tonus, the result probably of reflex influences.

A cortical representation for laryngeal respiratory movements has been determined by Semon and Horsley in different classes of animals. In the cat especially, stimulation of the border of the olfactory sulcus gives rise to complete abduction of the vocal bands on both sides. The representation is therefore bilateral.

The *phonatory center* was located by the same investigators in the medulla near the ala cinerea and the upper border of the calamus scriptorius. Stimulation of this area was invariably followed by bilateral adduction of the vocal bands and closure of the glottis.

A cortical representation for phonatory movements also was located in the lower portion of the precentral convolution, near the anterior border. Stimulation of this area gives rise to marked adduction of both vocal bands, indicating that the representation is also bilateral.

Faradic stimulation of the inferior laryngeal nerve during slight ether anesthetization gives rise to closure of the glottis; the same stimulation, however, during deeper anesthetization gives rise to opening or dilatation of the glottis, a fact indicating that either the adductor muscles or their nerve terminals are depressed by the action of the ether before the muscles and nerves of opposite function. The superior laryngeal nerves contain motor fibers for the crico-thyroid muscles. Stimulation of the nerve gives rise to contraction of the muscle and increased tension of the vocal bands. It is believed that these fibers are derived originally from the efferent fibers of the glosso-pharyngeal nerve. The remaining fibers of the superior laryngeal endow the upper portion of the larynx with extreme sensibility which to a certain extent protects the air-passages against the entrance of foreign bodies. Irritation of the terminal filaments of this nerve by particles of food, solid or liquid, gives rise to marked reflex spasm of the adductor muscles and closure of the glottis, followed by a strong expiration blast of air from the lungs by which the offending particles are removed. *Division* of this nerve on both sides is followed by a paralysis of the crico-thyroid muscles, a lowering of the tension of the vocal bands, and a loss of sensibility of the laryngeal mucous membrane.

CHAPTER XXVI.

THE SPECIAL SENSES.

It is one of the functions of the nerve system to bring the individual into conscious relation with the external world. This is accomplished in part through the intermediation of afferent nerves, connected peripherally, with highly specialized terminal organs, and centrally, with specialized areas in the cerebral cortex.

Excitation of the terminal organs by material changes in the environment develops nerve impulses which, transmitted to the cortical areas, evoke sensations. These sensations, differing in character from those vague ill-defined sensations—*e. g.*, fatigue, well-being, discomfort, etc.—caused by material changes occurring within the body, are termed special sensations—*e. g.*, touch; pressure; pain; temperature; taste; smell; light and its varying qualities, intensity, hue, and tint; sound and its varying qualities, intensity, pitch, and timbre.

The terminal organs which receive the impress of the external world are the skin, tongue, nose, eye, and ear, and collectively constitute the special sense-organs. The physiologic mechanisms which underlie and develop these special sensations are known respectively as the tactile, gustatory, olfactory, optic, and auditory. Each mechanism responds to but a single form of stimulus and to no other. Thus, the stimulus for the skin is mechanic pressure; for the tongue, soluble organic and inorganic matter; for the nose, volatile or gaseous matter; for the eye, ether vibrations; for the ear, atmospheric undulations. These stimuli alone are adequate to the physiologic excitation of the different mechanisms.

The factors involved in the production of the sensations include (1) a special physical stimulus; (2) a specialized terminal organ; (3) an afferent nerve pathway, and (4) a specialized receptive sensor cell in the cerebral cortex.

Though the resulting sensations in each instance differ widely in their characteristics, it is difficult to present a satisfactory explanation for these differences. If it be assumed that the nerve impulses which ascend the different nerves of special sense are alike in quality, then it must be admitted that the character of the sensation is the expression of a specialization and organization of the cortical area. If, on the other hand, specialization of the cortex is denied, then there must be admitted a specialization of the peripheral organ—with a resulting difference in quality or rapidity of the nerve impulses which would impress or excite the non-specialized cortex in such a way as to call forth the characteristic sensation. It is possible, however, that neither supposition is wholly correct, and that the character of the sensation depends on the construction and adaptation of the entire sense apparatus to the character of the stimulus.

Whatever the conditions for their origin and whatever their characteristics, sensations in themselves do not constitute knowledge; they are but elementary states of consciousness, raw materials out of which the mind elaborates conceptions and forms judgments as to the character of any given object in comparison with former experiences.

THE SENSE OF TOUCH.

The physiologic mechanism involved in the sense of touch includes the skin and the mucous membrane lining the mouth, the afferent nerves, their cortical connections, and nerve-cells in the cortex of the parietal lobe.

Peripheral excitation of this mechanism develops nerve impulses which, transmitted to the cortex, evoke sensations of touch and temperature. To the skin, therefore, is ascribed a touch sense and a temperature sense. Of the touch sensations two kinds may be distinguished: viz., pressure sensations and place sensations. With the contact of an external body there arises the perception not only of the pressure, but also the perception of the place or locality of the contact. In accordance with this, it is customary to attribute to the skin a pressure sense and a location sense.

The specific physiologic stimuli to the terminal organs in the skin and oral mucous membrane are mechanic pressure and thermic vibrations.

The Skin.—The skin, which constitutes the basis for the sense of touch, covers and closely invests the entire body. It varies in thickness and delicacy in different regions, though its structure is everywhere essentially the same. As the physiologic anatomy of the skin has elsewhere been detailed (page 486), it is only necessary to state here that it is divided into a deep and a superficial layer. The *former*, known as the *derma*, consists of an inner layer of rather loose connective tissue and an outer layer of condensed connective tissue. The *latter*, known as the *epidermis*, consists of an inner layer of pigment cells and a thick outer layer of epithelial cells. The derma is characterized by the presence of elevations (papillæ) which are everywhere extremely abundant. Throughout the derma ramify blood-vessels and nerves.

The Peripheral or Terminal Organs.—Between the contact surface and the afferent nerves specialized structures are found which serve as intermediates between the stimulus, on the one hand, and the afferent nerves, on the other hand. By virtue of their structure they are far more irritable than the nerve-fibers and hence respond more quickly to the physiologic stimulus than the nerve-fiber itself. To these specialized organs, found not only in the skin but in other sense-organs as well, the term peripheral or terminal organ is given. It is these structures that are primarily excited to activity by the physiologic stimulus, and that in turn arouse the nerve to activity. Peripheral organs are to be regarded as special modes of termination of afferent nerves and adapted for the impress of a specific stimulus. The peripheral organs of afferent nerves found in the skin and oral mucous membrane present a variety of forms, some of which are as follows:

1. *Free Endings.*—These are pointed or club-shaped processes, the ultimate terminations of afferent nerve-fibrils, found in and among epidermic cells.
2. *Tactile Cells.*—These are oval nucleated bodies found in the deeper layers of the epidermis. They rest upon or are embraced by a crescentic shaped body, the *tactile meniscus*, which in turn is directly connected with the nerve-fibril and probably a modification of it (Fig. 297).
3. *The Corpuscles of Meissner and Wagner.*—In the papillæ of the derma, especially in the palm of the hand and in the finger-tips, are found elliptical bodies consisting of a connective-tissue capsule containing a number of tactile discs with which the nerve-fibrils are connected. If the afferent nerve is traced to the capsule, it is found to lose both its neurilemma and medulla, after which the naked fibril penetrates the capsule, breaks up into a number of branches, and after pursuing a more or less spiral course becomes connected with the tactile discs (Fig. 298).
4. *Hair Wreaths.*—Just below the openings of the sebaceous gland the hair-follicles are surrounded by naked axis-cylinder fibrils in the form of a wreath, which in all probability terminate in the cells of the external root-sheath. These, too, are to be regarded as part of the touch apparatus.
5. *Corpuscles of Vater or Pacini.*—These are oval-shaped structures found along the nerves distributed to the palms of the hands and the soles of the feet, on the nerves distributed to the external genital organs, to joints and other structures. They consist of a thick capsule of lamellated connective tissue in the interior of which is a bulb resembling granular protoplasm. The axis-cylinder of the nerve-fiber enters the capsule and becomes connected with the bulb (Fig. 299).

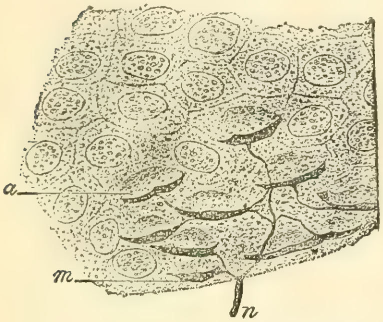

FIG. 297.—TACTILE CELLS FROM SNOUT OF PIG. *a.* Tactile cell. *m.* Tactile disc. *n.* Nerve-fiber.—(*Stirling.*)

Other forms of peripheral organs are found in special regions of the skin as well as in different animals.

Touch Sense.—The area, stimulation of which evokes sensations of touch, is coextensive with the skin and that limited portion of the mucous membrane lining the mouth. Careful stimulation of the skin by means of a fine stiff bristle has revealed the fact, however, that the touch area is not continuous, but discrete, presenting itself under the form of small areas or spots, separated by relatively large areas insensitive to the same agent. Stimulation of these spots always calls forth a sensation of touch. For this reason they are known as "touch spots." The number of such spots in any given area of skin varies considerably. Thus, in the skin of the calf fifteen such spots have been counted in a square centimeter. In the palm of the hand from forty to fifty have been counted in an area of the same extent. They are also especially abundant in the immediate neighborhood of the hair-follicles.

The peripheral end-organ associated with the touch spots in the neighborhood of a hair-follicle is in all probability the wreath of nerve-fibrils surrounding the follicle. In regions devoid of hairs the end-organ is the Meissner corpuscle, for in the palmar surface of the last phalanx of the index-finger, where the touch sense is quite acute, about 20 corpuscles are present in each square millimeter of surface. The specific stimulus necessary to evoke the sensation of touch is a deformation of the skin; and the greater this is within physiologic limits, the more pronounced is the sensation.

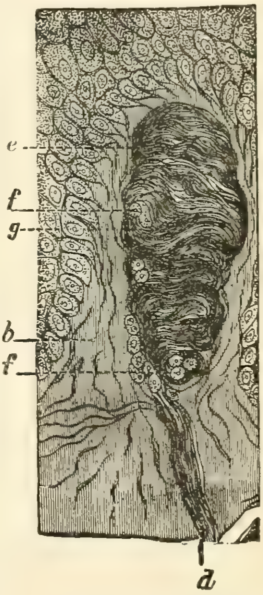

FIG. 298.—TOUCH-CORPUSCLE OF MEISSNER AND WAGNER. *b.* Papilla of cutis. *d.* Nerve-fiber of touch-corpuscle. *e, f.* Nerve-fiber in touch-corpuscles. *g.* Cells of Malpighian layer.—(*From Stirling.*)

Pressure Sense.—The contact of an external body is attended by a certain amount of pressure, which, however, must attain a certain degree before the sensation can be evoked. This is known as the threshold value, or the degree of liminal intensity. Since the sensations are the result of pressure, they are termed pressure sensations, and their intensity may be expressed in terms of pressure.

The sensitivity of the skin as determined by the pressure sense varies in different regions of the body and in accordance with the size of the area pressed. Thus, the liminal intensity of a stimulus for an area of nine square millimeters for the skin of the forehead is 0.002 gram; for the flexor aspect of the forearm, 0.003 gram; and for the hips, thigh, and abdomen, 0.005 gram; for the palmar surface of the finger, 0.019 gram; for the heel, 1 gram. The delicacy of the sense of touch is measured by the slight increase or decrease in the intensity of the stimulus that will produce an appreciable change in the intensity of the sensation. Not all changes in the stimulus, however, are attended by a change in the sensation. It has been determined that the latter will change only when the former changes in a definite ratio, which for the volar surface of the third phalanx of the index-finger is as 29 is to 30. Thus, other things being equal, a sensation caused by a given weight will only change with moderate stimulation when one-thirtieth of the weight is either added or subtracted. The ratio of change, however, varies in different regions of the body: thus, for the back of the hand the ratio varies from one-tenth to one-twentieth; for the tongue, one-thirtieth to one-fortieth. The difference of stimulus necessary to evoke a sensation is known as the threshold difference. It seems to be a law not only for the skin, but for other senses as well, that a change in the intensity of a sensation, to an appreciable extent, will occur only when the objective stimulus changes in a definite ratio. This ratio, however, will vary not only in different regions of the skin, in different individuals, but with the sense-organ investigated.

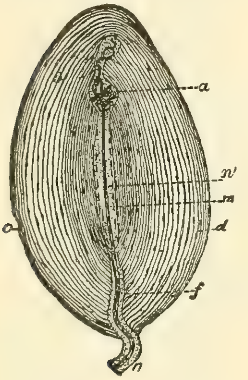

FIG. 299.—PACINIAN CORPUSCLES. *c.* Capsules. *d.* Endothelial lining separating the latter. *n.* Nerve. *f.* Funicular sheath of nerve. *m.* Central mass. *n'.* Terminal fiber; and *a.* Where it splits up into finer fibrils. —(*Stirling.*)

Place Sense.—The sensation evoked by stimulation of the skin is always, under normal conditions, referred to the place stimulated. This holds true not only for two or more points near or widely separated on the same side, but also for corresponding points on opposite sides of the body, even when the stimuli have the same intensity and are simultaneously applied. The cause for this localizing power is to be found in a difference in the quality of the sensation related in some way to the part stimulated. Each cutaneous area is supposed to give to the tactile sensation a quality or local sign by virtue of which the mind is enabled to localize the point of contact.

Each cutaneous area which has a local sign of its own is known as a sensory circle, for the reason that the mind does not refer the sensation to a point, but to an area more or less circular in outline. The skin may therefore be regarded as composed of myriads of such circles varying in size in different regions of the body.

The delicacy of the localizing power in any part of the skin is determined by testing the power which the part possesses, of distinguishing the sensations produced by the contact of the points of a pair of compasses placed close together. The distance to which the points must be separated in order to evoke two separate recognizable sensations is a measure of the diameter of the sensory circle. Within this circle the two sensations become fused into one sensation. The discriminative sensibility of different regions as determined by compass points is shown in the following table; the numbers represent the distances at which two sensations are recognized:

	MM.
Tip of tongue,	1.1
Palmar surface of third phalanx of index finger,	2.2
Red surface of lips,	4.5
Palmar surface of first phalanx of finger,	5.5
Tip of nose,	6.8
Palm of hand,	8.9
Lower part of forehead,	22.6
Dorsum of hand,	31.6
Dorsum of foot,	40.6
Middle of the back,	67.7

The discriminative sensibility of any portion of the body is a function of its mobility. This is shown by the fact that it increases rapidly from the shoulders to the fingers and from the hips to the toes.

The Temperature Sense.—The sensations of heat and cold which are experienced from time to time are caused by changes in the temperature of the skin produced in a variety of ways. As these sensations are specifically different from those of touch, as well as different from each other, it is highly probable that for each sensation there are special nerve-endings distributed throughout the skin. Investigations have shown that all over the skin there are innumerable spots of varying size which if stimulated evoke sensations of heat or cold. Such points are termed heat and cold spots. Each responds to but one kind of stimulus. A warm object applied to a heat spot will evoke a sensation of warmth. It will have no effect on the cold spot. The reverse is also true. Between the cold and heat spots there are areas that are neutral, insensitive to either heat or cold. The cold spots are more numerous than the heat spots in almost all regions of the body. (See Fig. 300.)

The sensitivity of the skin to temperature changes is very acute, as shown by the fact that even 0.05° C. is readily appreciable. This holds true, however, only when the temperature of the object lies between 27° and 33° C. This capability varies in different regions of the skin, and depends on the number of heat and cold spots present, the thickness of the epidermis, the thermal conductivity of the object touching it, and the extent to which it is habitually exposed or protected.

The physiologic stimulus to the thermic end-organs is the passage of heat through the skin from the interior of the body to the surrounding air. If the radiation is continuous and uniform, the end-organs soon adapt themselves to the temperature of the surrounding air and the sensation of heat, under physiologic conditions, is not evoked. If there is a sudden rise in the external temperature caused by natural or artificial means, which diminishes the radiation, the temperature of the skin will at once rise, the end-organs will be stimulated, and a sensation of warmth developed. If, on the other hand, there is a sudden fall in temperature and an increased radiation, the temperature of the skin will fall, the end-organs will be stimulated, and a sensation of cold developed. Experiment also teaches that the intensity of a warm or cold sensation will depend on the existing temperature of the skin, and not upon the absolute temperature of the object. Thus, water as 20° C. will evoke a sensation of heat or cold according as the skin has previously been cooled below or warmed above this temperature.

The Muscle Sense.—As a result of the activities of the musculature of the body or even of its individual parts, there arises in consciousness a series of sensations, which are termed muscle sensations. These sensations give rise to the perception—

1. Of the direction and duration of both passive (due to external causes) and active movements (due to internal, volitional efforts) which take place without hindrance;
2. Of the resistance offered to movements by external bodies; and—
3. Of the posture of the body or of its individual parts.

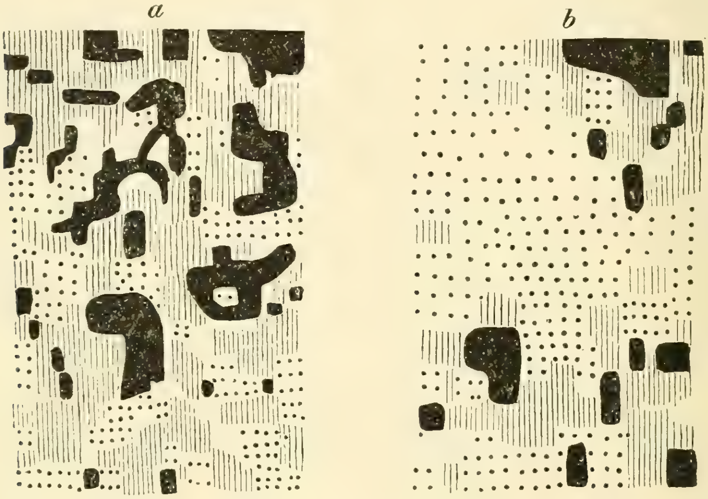

Fig. 300.—Cold and Hot Spots from the Anterior Surface of the Forearm. *a.* Cold spots. *b.* Hot spots. The dark parts are the most sensitive, the hatched the medium, the dotted the feebly and the vacant spaces the non-sensitive.—(*Landois and Stirling.*)

As to the seat of the physiologic processes which precede and underlie the development of the sensations two views, at least, may be advanced, viz.:

1. That the processes are central in origin and partake of the nature of a discharge of nerve impulses from the nerve-cells through the motor nerves to the muscles, the entire process being accompanied by sensation. This is known as the innervation theory.
2. That the processes are peripheral in origin, initiated by stimulation of specialized end-organs in the muscles and tendons which are

connected through the intermediation of afferent nerves with nerve-cells in the cerebral cortex.

The physiologic mechanism subserving the muscle sense, according to the second theory, now held by many physiologists, thus involves peripheral end-organs, afferent nerves, their cortical connections and nerve-cells in the cerebral cortex at or near the junction of the superior and inferior parietal convolutions.

The End-organs.—These are small fusiform structures found in and among the muscle bundles of all the muscles of the body with the exception of the diaphragm and eye muscles. In the muscles of the arm and in the small muscles of the hand they are especially abundant. From their shape they are known as *muscle spindles.* They vary in length from 2 to 12 mm. and in breadth from 0.15 to 0.4 mm. Each spindle (Fig. 301) consists of a connective-tissue capsule containing from two to ten longitudinally arranged striated muscle fibers of fine diameter. In the middle or equatorial region of these *intra-fusal* fibers there is frequently found a quantity of non-striated protoplasmic matter. The spindle is supplied with both sensor and motor nerves.

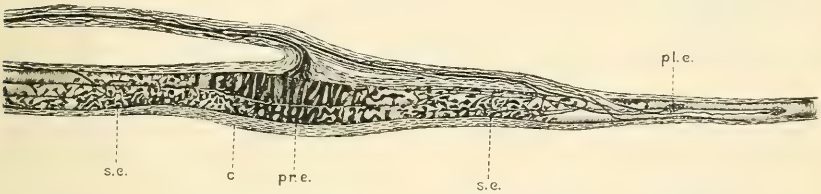

FIG. 301.—A NEURO-MUSCLE SPINDLE OF A CAT. (*Ruffini.*) *c.* Capsule. *pr. e.* Primary ending. *s. e.* Secondary ending. *pl. e.* Plate ending. (All these are probably sensor in function.)—(*Starling's "Physiology."*)

The sensor fiber loses its external investments as it approaches the capsule. The naked axis-cylinder then penetrates the capsule, and after dividing several times terminates in a ribbon-like or spiral manner around the intra-fusal muscle fiber. This ending was described by and is known as Ruffini's "annulo-spiral ribbon." The motor nerve also penetrates the capsule and terminates in the polar extremities of the intra-fusal fiber. Sensor end-organs supposed to be connected with the muscle sense are also found in the tendons of muscles.

Afferent Nerves.—That muscles are abundantly supplied with afferent nerves has been proved by different methods of investigation. With histologic methods Sherrington has traced afferent fibers from the muscle spindles directly into the spinal nerve ganglia. The contractions of muscles from electric stimulation as well as the contractions known as muscle cramp, due to unknown agents, give rise to sensations of pain, a fact which indicates the presence in muscles of afferent or sensor nerves.

Cortical Area.—Pathologic findings have shown that an impairment or a loss of the muscle sense is associated with destructive lesions of perhaps the super and sub-parietal convolutions (Figs. 252, 253). In a case reported by Starr the removal of a small tumor in the pia mater situated over the junction of the superior and inferior parietal lobules was followed by a loss of the muscle sense and marked ataxia in the right hand for a period of six weeks, after which recovery took place. These symptoms were attributed to injury of the cortex from unavoidable surgical procedures.

The muscle sensations, as stated in foregoing paragraphs, form the basis of the perception not only of the direction and the duration of a body movement and the resistance experienced, but also of the position and the tension of the muscle groups. The latter fact more especially makes it possible for the mind to direct the muscles and to graduate the energy necessary to the accomplishment of a definite purpose.

Active Touch.—Active touch or the application of the fingers to the surfaces of external objects implies the coöperation of the skin and the muscles. The sensations which are evoked are combinations of contact and muscle sensations. The union of these sensations forms the basis of the perception of hardness, softness, smoothness, and roughness of bodies.

THE SENSE OF TASTE.

The physiologic mechanism involved in the sense of taste includes the tongue. the gustatory nerves (the chorda tympani and the glossopharyngeal), their cortical connections and nerve-cells in the gray matter of the fourth temporal convolutions. The peripheral excitation of this apparatus gives rise to nerve impulses which transmitted to the brain evoke the sensations of taste. The specific physiologic stimulus is matter, organic and inorganic, in a state of solution.

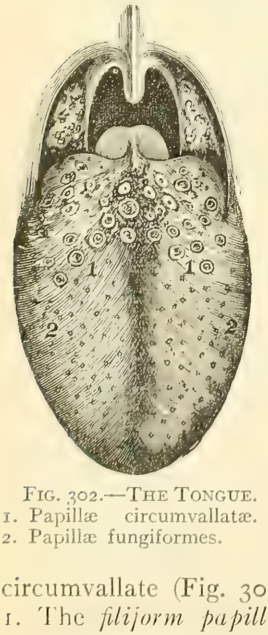

FIG. 302.—THE TONGUE.
1. Papillæ circumvallatæ.
2. Papillæ fungiformes.

The Tongue.—The tongue consists of both intrinsic and extrinsic muscles, in virtue of which it is susceptible of both a change in shape and position. The movements of the tongue, though not essential to taste, are made use of in the finer discrimination of tastes.

The tongue is covered over by mucous membrane continuous with that lining the oral cavity. The dorsum of the tongue presents a series of papillæ richly supplied with blood-vessels and nerves. Of these there are three varieties, the filiform, the fungiform, and the circumvallate (Fig. 302).

1. The *filiform papillæ,* the most numerous, cover the anterior two-thirds of the tongue; they are conical or filiform in shape and

covered with horny epithelium which is often prolonged into filamentous tufts.

2. The *fungiform papillæ*, found chiefly at the tip and sides of the tongue, are less numerous but larger than the preceding and of a deep red color.
3. The *circumvallate papillæ*, from eight to ten in number, are situated at the base of the tongue arranged in the form of the letter ∧ They consist of a central projection surrounded by a wall or circumvallation from which they take their name.

The Peripheral End-organs. The Taste-buds.—Embedded in the epithelium covering the mucous membrane not only of the tongue but of the palate and posterior surface of the epiglottis are small ovoid bodies which from their relation to the gustatory nerves are regarded as their peripheral end-organs and known as taste-buds or taste-beakers. Each bud is ovoid in shape (Fig. 303). Its base rests on the tunica propria; its apex comes up to the epithelium, where it presents a narrow funnel-shaped opening, the *taste-pore*. The wall of the bud is composed of elongated curved epithelium. The interior contains narrow spindle-shaped neuro-epithelial cells provided at their outer extremity with stiff hair-like filaments which project into the taste-pore.

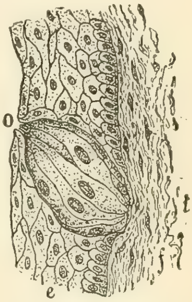

Fig. 303.—Taste-bud from Circumvallate Papilla of a Child. The oval structure is limited to the epithelium (*e*) lining the furrow, encroaching slightly upon the adjacent connective tissue (*f*); *o*, taste-pore through which the taste-cells communicate with the mucous surface. —(*After Piersol.*)

The neuro-epithelial cells are in physiologic relation with the nerves of taste. The terminal branches, after entering the bud at its base, develop fine tufts which come into contact with the cells. That the taste-buds are connected with the nerves of taste is rendered probable from the fact of their degeneration after division of the nerves.

The Taste Area.—The taste area, though confined for the most part to the tongue, extends itself in different individuals to the mucous membrane of the hard palate, to the anterior surface of the soft palate, to the uvula, the anterior and posterior half arches, the tonsils, the posterior wall of the pharynx, and the epiglottis.

The Taste Sensations.—The sensations which arise in consequence of impressions made by different substances on the peripheral apparatus of this area are in so many instances combinations of taste, touch, temperature, and smell that they are extremely difficult of classification. Nevertheless four primary tastes can be recognized: viz., bitter. sweet, acid or sour, salt or saline. Though the contact of any bitter, sweet, acid, or salt substance with any part of the tongue will, if the substance be present in sufficient quantity or concentration, develop a corresponding sensation, some regions of the tongue are more sensitive and responsive than others. Thus, the posterior portion is more sensitive to bitter substances than the anterior; the reverse is true for sweet substances and perhaps for acids and salines.

The intensity of the resulting sensation in any given instance will depend on the degree of concentration of the substance, while its massiveness will depend on the area affected.

THE SENSE OF SMELL.

The physiologic mechanism involved in the sense of smell includes the nasal fossæ, the olfactory nerves, the olfactory tracts, and nerve-cells in those areas of the cortex known as the uncinate convolution and anterior part of the gyrus fornicatus. Peripheral stimulation of this mechanism develops nerve impulses which, transmitted to the cortex, evoke the sensations of odor. The specific physiologic stimulus is matter in the gaseous or volatile state.

The Nasal Fossæ.—The nasal fossæ are irregularly shaped cavities separated by a vertical septum formed by the perpendicular plate of the ethmoid bone, the vomer, and the triangular cartilage. The outer wall presents three recesses separated by the projection inward of the turbinated bones. Each fossa opens anteriorly and posteriorly by the anterior and posterior nares, the latter communicating with the pharynx. Both fossæ are lined throughout by mucous membrane. The upper part of the fossa is known as the olfactory, the lower portion as the respiratory region. In the former, the mucous membrane over the septum and superior turbinated bone is somewhat thicker than elsewhere and covered with a neuro-epithelium which constitutes—

The Peripheral End-organ.—This consists of a basement membrane supporting two kinds of cells, the olfactory and the sustentacular. The olfactory cells are bipolar nerve-cells, the center of which contains a large spheric nucleus. The peripheral pôle is cylindric or conic in shape and provided at its extremity with several hair-like processes. The central pole becomes the axon process and passes directly to the olfactory bulb.

The sustentacular cells are epithelial in character and, as their name implies, support or sustain the olfactory cells.

For the appreciation of odorous particles the air must be drawn through the nasal fossæ with a certain degree of velocity. If the particles are widely diffused in the air, they must be drawn not only more quickly but more forcibly into contact with the olfactory hairs, as in the act of sniffing, the result of short energetic inspirations. To many substances the olfactory apparatus is extremely sensitive. Thus, it has been shown that a particle of mercaptan the actual weight of which was calculated to be $\frac{1}{460000000}$ of a milligram gave rise to a distinct sensation.

The Olfactory Sensations.—The sensations which arise in consequence of the excitation of the olfactory apparatus are very numerous and their classification is extremely difficult. For this reason it is customary to divide them into two groups: viz., agreeable and disagreeable, in accordance with the feelings they excite in the individual. As the olfactory sensations give rise to feelings rather than ideas, this sense plays in man a subordinate part in the acquisition of knowledge. In lower animals this sense is employed for the purpose of discovering and securing food, for detecting enemies and friends, and for sexual purposes. In land animals the entire olfactory apparatus is well developed and the sense keen; in some aquatic animals, as the dolphin, whale, and seal, the apparatus is poorly developed and the sense dull.

CHAPTER XXVII.

THE SENSE OF SIGHT.

The physiologic mechanism involved in the sense of sight includes the eyeball, the optic nerve, the optic tracts, their cortical connections, and nerve-cells in the cuneus and adjacent gray matter. Peripheral stimulation of this mechanism develops nerve impulses which transmitted to the cortex evoke (1) the sensation of light and its different qualities—colors; (2) the perception of light and color under the form of pictures of external objects; and (3) in connection with the ocular muscles, the production of muscle sensations by which the size, distance, and direction of objects may be judged.

The specific physiologic stimulus to the terminal end-organ, the retina, is the impact of ether vibrations. In general, it may be said that, at least for the same color, the intensity of the objective vibration determines the intensity of the sensation.

THE PHYSIOLOGIC ANATOMY OF THE EYEBALL.

The eyeball is situated at the fore part of the orbit cavity, and in such a position as to permit of an extensive range of vision. It is loosely held in position by a fibrous membrane, the capsule of Tenon, which is attached, on the one hand, to the eyeball itself, and, on the other, to the walls of the orbit cavity. Thus suspended, the eyeball is susceptible of being moved in any direction by the contraction of the muscles attached to it.

The ball is spheroid in shape, measuring about 24 millimeters in its anterio-posterior diameter and a little less in its transverse and vertical diameters. When viewed in profile, it is seen to consist of the segments of two spheres, of which the posterior is the larger, occupying five-sixths, and the anterior is the smaller, occupying one-sixth of the ball. It is composed of several concentrically arranged membranes enclosing various refracting media essential to vision.

The membranes, enumerating them from without inward, are as follows: the sclera and cornea, the chorioid and iris, and the retina. The refracting media are the aqueous humor, the crystalline lens, and the vitreous humor.

The Sclera and Cornea.—The *sclera* is the thick opaque membrane covering the posterior five-sixths of the ball. It is composed of layers of connective tissue which are arranged transversely and longitudinally. It is pierced posteriorly by the optic nerve about

3 or 4 millimeters internal to the optic axis. By virtue of its firmness and density the sclera gives form to the eyeball, protects delicate structures enclosed by it, and serves for the attachment of the muscles by which the ball is moved (Figs. 304, 309.) The *cornea* is the transparent membrane forming the anterior one-sixth of the ball. It is nearly circular in shape, measuring in its horizontal meridian 12 mm., in its vertical meridian 11 mm. The curvature is therefore sharper in the latter than in the former. The radius of curvature of the anterior surface at that central portion ordinarily used in vision is 7.829 mm.; that of the posterior surface about 6 mm.

The substance of the cornea is made up of thin layers of delicate transparent fibrils of connective tissue continuous with those found in the sclera. Lymph-spaces are present throughout the cornea, in which are to be found lymph-corpuscles. The anterior surface of the cornea is covered with several layers of nucleated epithelium supported by a structureless membrane, the *anterior elastic lamina.* The posterior surface also is covered by a layer of epithelium supported by a similar membrane, the membrane of Descemet, which at its periphery becomes continuous with the iris. At the junction of the cornea and sclera there is a circular groove, known as the canal of Schlemm.

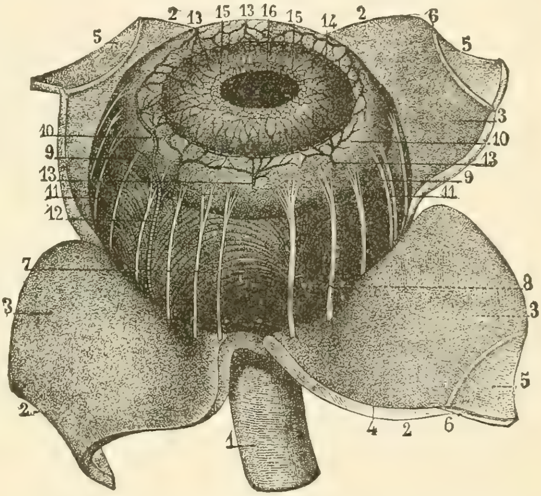

FIG. 304.—CHORIOID COAT OF THE EYE. 1. Optic nerve. 2, 2, 2, 2, 3, 3, 3, 4. Sclerotic coat divided and turned back to show the chorioid. 5, 5, 5, 5. The cornea, divided into four portions and turned back. 6, 6. Canal of Schlemm. 7. External surface of the chorioid, traversed by the ciliary nerves and one of the long ciliary arteries. 8. Central vessel into which open the vasa vorticosa. 9, 9, 10, 10. Chorioid zone. 11, 11. Ciliary nerves. 12. Long ciliary artery. 13, 13, 13, 13. Anterior ciliary arteries. 14. Iris. 15, 15. Vascular circle of the iris. 16. Pupil.—(*Sappey.*)

The Chorioid, Iris, Ciliary Muscle, and Ciliary Processes.—The *chorioid* is the dark brown membrane which extends forward nearly to the cornea, where it terminates in a series of folds, the ciliary processes. Posteriorly, it is pierced by the optic nerve. It is composed largely of blood-vessels, arteries, capillaries, and veins, supported by connective tissue. Externally it is loosely connected to the sclera; internally it is lined by a layer of hexagonal cells containing black pigment which, though usually described as a part of the chorioid, is now known to belong, embryologicly and physiologicly, to the retina. Lying within the outer layer of arteries and veins there is a thick layer of small arterioles and capillaries, known as the choriocapillaris. The chorioid with its contained blood-vessels bears an important relation to the nutrition and function of the eye. It provides a free supply of lymph and presents a uniform temperature to the retina in contact with it.

The *iris* is the circular, variously colored membrane in the anterior part of the eye just behind the cornea. It presents a little to the nasal side of the center a circular opening, the *pupil.* The outer or circumferential border is united by connective tissue to the cornea, sclera, and ciliary muscle; the inner border forms the boundary of the pupil. The iris consists of a framework of connective tissue supporting blood-vessels, muscle-fibers, and pigmented connective-tissue cells. The anterior surface is covered by a layer of cells continuous with those covering the posterior surface of the cornea. The posterior surface is formed by a thin structureless membrane supporting a layer of pigment cells continuous with those lining the chorioid. The color which the iris presents in different individuals depends on the relative amount of pigment in the connective-tissue corpuscles. In blue eyes the pigment is wanting. In gray, brown, and black eyes the pigment is present in progressively increasing amounts. The blood-vessels are connected with those of the chorioid coat.

The muscle-fibers are of the non-striated variety and arranged in two sets, one circularly, the other radially, disposed.

The circular fibers are found close to the pupil near the posterior surface of the iris. Contraction of this band of fibers diminishes, relaxation increases, the size of the pupil. This muscle is known as the *sphincter pupillæ* or *sphincter iridis.*

The radial fibers form a more or less continuous layer in the posterior part of the iris, extending from the margin of the pupil, where they blend with the circular fibers, to the outer border. Contraction of the fibers enlarges the size of the pupil. The muscle is known as the *dilatator pupillæ.*

The nerves exciting the *sphincter pupillæ* to action are the ciliary nerves, axons of nerve-cells located in the ciliary or ophthalmic ganglion. Stimulation of these fibers gives rise to contraction of the sphincter and diminution in the size of the pupil. The nerves exciting the *dilatator pupillæ* to action are axons of nerve-cells located in the superior cervical ganglion. They reach the iris by way of the cervical sympathetic, the ophthalmic division of the fifth, and the long ciliary nerve. Stimulation of these nerves is followed by contraction of the dilatator and enlargement in the size of the pupil. Both the ciliary and superior cervical ganglia are in relation with pre-ganglionic fibers coming from the central nerve system. (See page 589.)

The *ciliary muscle* is a gray circular band about two millimeters in width, consisting of non-striated muscle-fibers. The majority of these fibers pursue a radial or meridional direction. Taking their origin from the junction of the sclera, cornea, and iris, they pass backward to be inserted into the chorioid coat opposite the ciliary processes. The inner portion of the muscle is interrupted by bundles of fibers which pursue a circular direction. (Fig. 305.) They collectively constitute the *annular* or *ring muscle* of Müller. The ciliary muscle in common with the circular fibers of the iris receives its nerve-supply direct from the nerve-cells in the ciliary ganglion. Contraction of the ciliary muscle tenses the chorioid coat, and for this reason it is frequently termed the *tensor chorioideæ*.

The Retina.—The retina is the internal coat of the eye, extending forward almost to the ciliary processes, where it terminates in an indented border, known as the *ora serrata*. In the living condition it is clear, transparent, and pink in color. After death it becomes opaque. The retina is abundantly supplied with blood-vessels, derived from the *arteria centralis retinæ*, a branch of the ophthalmic, which pierces the optic nerve near the sclera, runs forward in its center, to the retina, in which its terminal branches are distributed. The veins arising from the capillary plexus leave the retina by the same route.

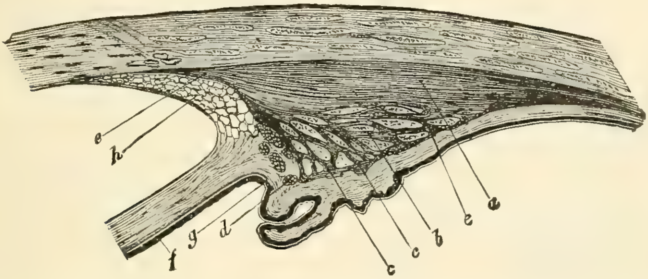

FIG. 305.—SECTION THROUGH THE CILIARY REGION OF THE HUMAN EYE. *a*. Radiating bundles of the ciliary muscle. *b*. Deeper bundles. *c*. Circular network. *d*. Annular muscle of Müller. *e*. Tendon of ciliary muscle. *f*. Muscle-fibers on posterior side of the iris. *g*. Muscles on the ciliary border of the same. *h*. Ligamentum pectinatum.—(*After Iwanoff.*)

In the posterior portion of the retina, at a point corresponding with the axis of vision, there is a small oval area bout 2 mm. in its transverse and about 0.8 mm. in its vertical diameter. From the fact that it presents a yellow appearance, it is known as the *macula lutea*. This area presents in its center a depression with sloping sides, known as the *fovea centralis*. About 3.5 mm. to the nasal side of the macula is the point of entrance of the optic nerve.

The retina is remarkably complex in structure, presenting an appearance when viewed microscopically, something like that represented in Fig. 306, indicating that it is composed of different cellular elements arranged in layers. These have been named, from behind forward, as follows:

1. The layer of pigment cells.
2. The layer of rods and cones, or Jacobson's layer.
3. The external limiting membrane.
4. The outer nuclear or granular layer.
5. The outer molecular or reticular layer.
6. The inner nuclear or granular layer.
7. The inner molecular or reticular layer.
8. The layer of ganglion cells.
9. The layer of nerve-fibers.

Modern histologic methods of research have made it possible to reduce the retina, exclusive of the pigment cells, to three successive layers of nerve-cells, supported by a highly developed neuroglia, forming what has been termed the fibers of Müller. These nerve-cells are as follows:

1. The visual cells.
2. The bipolar cells.
3. The ganglion cells.

The relation of these nerve-cells one to another and to the supporting neuroglia tissue and the manner in which they unite to form the above-mentioned layers are schematicly shown in Fig. 307.

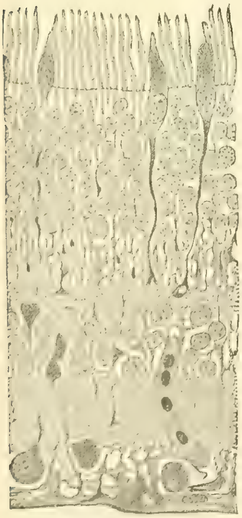
1. Pigment-layer (not shown).
2. Layer of rods and cones.
3. External limiting membrane.
4. Outer nuclear layer.
5. Outer molecular layer.
6. Inner nuclear layer.
7. Inner molecular layer.
8. Layer of ganglion cells.
9. Layer of nerve-fibers.

FIG. 306.—VERTICAL SECTION OF HUMAN RETINA. —(*Schaper.*)

The *pigment layer* is composed of hexagonal cells. Though formerly described as forming a part (the inner layer) of the chorioid, these cells belong embryologicly to the retina. From their retinal surface delicate pigmented processes extend into and between the rods and cones. On exposure to light these processes elongate and push themselves between the rods. In the dark they retract and withdraw into the cell-body.

The *visual cells* which form the layer of rods and cones are of two varieties, the rod-shaped and the cone-shaped.

The rod-shaped visual cells consist of a straight elongated cylinder extending through the entire thickness of Jacobson's membrane and a fine fiber containing a nucleus, which, after piercing the external limiting membrane, passes into the outer molecular layer, where it terminates in a spheric enlargement. The outer portion of the rod is clear and homogeneous, though containing a pigment known as visual purple or rhodopsin; the inner portion of the rod is slightly granular.

The cone-shaped visual cells also consist of two portions, a conic portion situated in Jacobson's membrane between the rods, and a fine fiber, containing a nucleus, which, after piercing the external limiting membrane, passes into the outer molecular layer, where it terminates in a fine tuft. The inner portion of the cone is thicker than the rod and rests on the limiting membrane; the outer portion tapers to a fine point and is known as the cone-style. The cones, as a rule, are shorter than the rods. The proportion of rods to cones varies in different parts of the retina, though there are on the average about fourteen rods to one cone. In the macula the rods are almost entirely absent, cones alone being present.

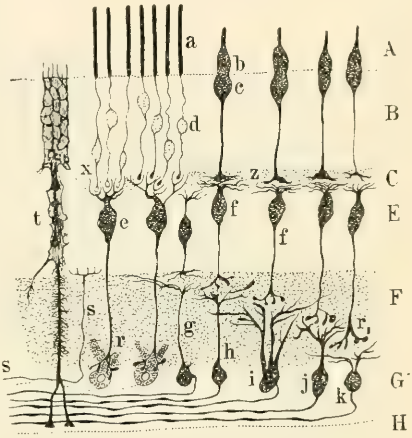

Fig. 307.—Cross-section of the Retina from a Mammal. A. Layer of rods and cones. B. Visual cells (outer granules). C. Outer molecular layer. E. Bipolar cells (inner granules). F. Inner molecular layer. G. Ganglion cells. H. Layer of nerve-fibers. a. Rods. b. Cones. e. Bipolar rod. f. Bipolar cone. r. Lower ramification of a bipolar rod. f. Lower ramification of a bipolar cone. g, h, i, j, k. Ganglion cells in various stages, branching from F. x, z. Bipolar contact of rods and cones. t. Müller's supporting fibers. S. Centrifugal nerve-fibers.—(*After Ramón y Cajal.*)

The layer of visual cells together with the neuroglia constitute the first three layers of the retina proper. The external limiting membrane is formed by the blending of the ends of neuroglia cells.

The *bipolar cells* consist of a central portion, found in the inner nuclear layer, from which are given off two processes which pass in opposite directions, one toward the visual cells, the other toward the ganglion cells. The former terminate in tufts which arborize around the tufts and spheric enlargements of the visual cells, and assist in the formation of the outer molecular layer; the latter terminate in similar tufts in the inner molecular layer.

The *ganglion cells* are arranged in a single layer, as a rule. They are large and nucleated. From the inner side of each cell there is given off a single axon which passes toward the center of the retina (forming the nerve-fiber layer), where it enters and assists in forming the optic nerve. From the outer side of the ganglion cell dendrites pass into and assist in forming the inner molecular layer. These dendrites come into physiologic relation with those of the inner processes of the bipolar cells.

Horizontally disposed nerve-cells are also present in the outer molecular layer in relation with the visual cells. Spongioblasts or amacrine cells are also present at the border of and in the inner molecular layer.

From the relation of the ganglion cells, from which the optic nerve-fibers take their origin, to the visual cells and the bipolar cells, the latter may be regarded as the *terminal visual organ*, the intermediate between the ether vibrations and the ganglion cell. The visual cells are directed toward the chorioid, away from the entering light, dipping into the pigment cells. They, with the pigment layer, are the elements by which the ether vibrations are transformed into nerve energy.

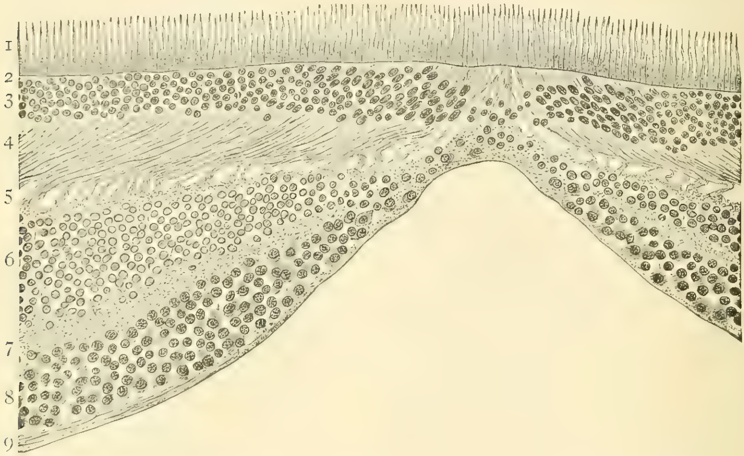

Fig. 308.—Horizontal Section through the Macula and Fovea of a Man Sixty Years Old. The section is not through the exact center of the fovea, for there are only cone visual cells and no remnants of the confluence of the inner granule and ganglion cell layers are present. 1. Cones. 2. External limiting membrane. 3. Outer nuclear layer. 4. Henle's fiber layer. 5. Outer molecular or reticular layer. 6. Inner nuclear layer. 7. Inner molecular or reticular layer. 8. Layer of ganglion cells. 9. Nerve-fiber layer.—(*After Schaper, Stöhr's "Histology."*)

In the fovea most of the retinal elements are wanting or are reduced in thickness. The cones alone are present. The cone-fibers with their nuclei are directed obliquely upward and outward along the slope of the fovea, to end in tufts which come into physiologic relation with the dendrites of the ganglion cells which at the top of the fovea are generally increased in number (Fig. 308).

It is estimated that the optic nerve contains about 500,000 nerve-fibers, and that for each fiber there are about 7 cones, 100 rods, and

7 pigment cells. In accordance with this estimate there would be about 3,500,000 cones, 50,000,000 rods, and 3,500,000 pigment cells. The distance between the centers of two adjacent cones in the fovea is 4 micromillimeters.

The *vitreous humor* is the largest of the refracting media and occupies by far the largest portion of the interior of the eyeball. From its position it gives support to the retina. Anteriorly it presents a concavity, in which the crystalline lens is lodged. The vitreous humor consists of water (97 per cent.), organic matter and salts, enclosed in a transparent membrane, the *tunica hyaloidea*. The mass of the vitreous humor is penetrated by a species of connective tissue.

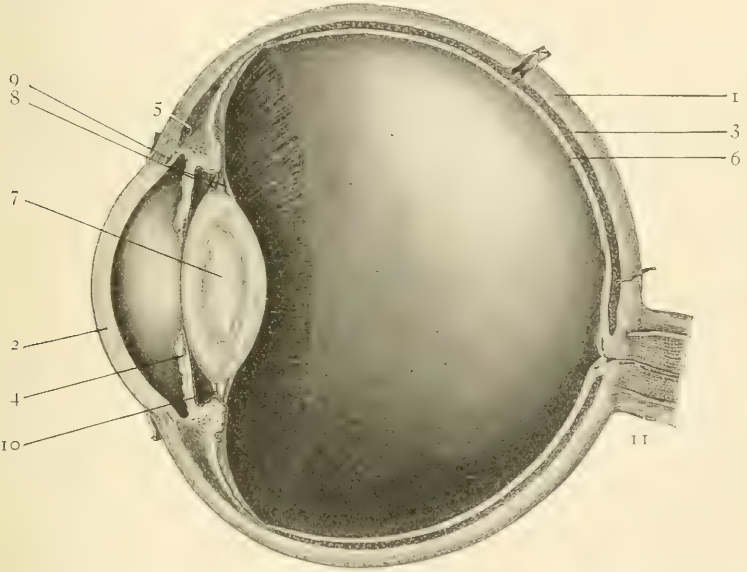

FIG. 309.—HORIZONTAL SECTION OF THE EYEBALL. 1. Sclera. 2. Cornea. 3. Chorioid. 4. Iris. 5. Ciliary muscle. 6. Retina. 7. Lens. 8. Suspensory ligament. 9. Canal of Schlemm. 10. Canal of Petit. 11. Optic nerve.—(*Deaver.*)

The *aqueous humor* is small in amount in comparison with the vitreous and is found in the space bounded by the cornea, the ciliary body, the suspensory ligament, and the lens. The projection of the iris into this space partially divides into an anterior and posterior portion or chamber. The aqueous humor is a clear, watery, alkaline fluid derived from or secreted by the capillary blood-vessels of the ciliary body. From this origin it passes through the pupil into the anterior chamber. It serves to keep the cornea tense and smooth. The ocular tension partly depends on the presence of this fluid in the eyeball. There is every reason for believing that there is a constant stream of fluid from the blood-vessels into the eye and from the eye through the spaces of Fontana at the base of the iris into the canal of

Schlemm, and so into the blood. Any interference with the exit of this fluid rapidly increases the ocular tension.

The *lens* is the transparent biconvex body situated just behind the iris, in the concavity of the vitreous. The thickness of the lens is 3.6 mm., the diameter about 9 mm. It consists of a transparent capsule containing elongated hexagonal fibers which, having their origin near the anterior central portion of the lens, pass out toward the margin, where they bend around to terminate in a triradiate figure on the opposite side. Chemicly the lens consists of water, a globulin body (crystallin), and salts.

The Suspensory Ligament.—The lens is held in position by the suspensory ligament, formed in part by the hyaloid membrane and in part by fibers derived from the ciliary processes. The former becomes attached to the posterior surface, the latter to the anterior surface of the lens near the equator. The space between the two layers of the ligament is the canal of Petit. The anterior surface of the ligament presents a series of plications conforming to corresponding plications on the surface of the ciliary processes.

The relations of all the parts entering into the structure of the eye are shown in Fig. 309.

THE PHYSIOLOGY OF VISION.

The Retinal Image.—The general function of the eye is the formation of images of external objects on the free ends of the percipient elements of the retina, the rods and cones. The existence of an image on the retina can be readily seen in the excised eye of an albino rabbit, when placed between a lighted candle and the eye of an observer. Its presence in the human eye can be demonstrated with the ophthalmoscope. It is this image, composed of focal points of luminous rays, which stimulates the rods and cones, which is the basis of our sight-perceptions, and out of which the mind constructs space relations of external objects. In only two essential respects does the image on the retina differ from the object, aside from the fact that the object has usually three, the image only two, dimensions—viz., in size and relative arrangement of its parts. Whatever the distance, the image is generally smaller than the object; it is also reversed, the upper part of the object becoming the lower part of the image, and the right side of the object the left of the image.

The Dioptric Apparatus.—The formation of an image is made possible by the introduction of a complex refracting apparatus consisting of the cornea, aqueous humor, lens, and vitreous humor. Without these agencies the ether vibrations would give rise only to a sensation of diffused luminosity. Rays of light emanating from any one point—that is, homocentric rays—arriving at the eye must traverse successively the different refracting media. In their passage from one to the other, they undergo at the surfaces changes in direction before they are finally converged to a focal point. In order to mathematically follow the rays in all their deviations through the media, to determine their focal points and to construct an image, a knowledge of the form of the refracting surfaces, the refractive indices of the different media, and the distances of the surfaces from one another must be known.

The following constants are now accepted: The radius of curvature of that portion of each refracting surface used for distinct vision is for the cornea 7.829 mm., for the anterior and posterior surfaces of the lens 10 and 6 mm., respectively. The indices of refraction of the different media are as follows: cornea and aqueous humor, 1.3365; lens, 1.4371; vitreous body, 1.3365. The distance from the vertex of the cornea to the lens is 3.6 mm.; the thickness of the lens, 3.6 mm.; the distance from the posterior surface of the lens to the retina, 15 mm. As the two surfaces of the cornea are practically parallel, and as the index of refraction of the aqueous humor is the same as that of the cornea, they may be regarded as but one medium. The refracting surfaces may therefore be reduced to the anterior surface of the cornea, the anterior surface of the lens, and the posterior surface of the lens.*

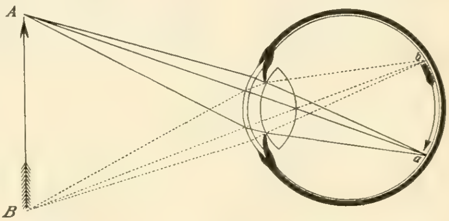

Fig. 310.—Refraction of Homocentric Rays and the Formation of an Image.

Parallel rays of light entering the eye pass from air, with an index of refraction of 1.00025, into the cornea, with an index of refraction of 1.3365. In passing from the rarer into the denser medium they undergo refraction in accordance with the laws of optics and are rendered somewhat convergent. The extent of this first refraction and convergence is sufficiently great to bring parallel rays, if continued, to a focus about 10 mm. behind the retina. This would be the condition in aphakia whether the lens is congenitally absent or has been removed by surgical procedures. Perfect vision, however, requires that the convergence of the light must be great enough to bring the focal point, the image, on the retina. This is accomplished by the introduction of an additional refracting body, the lens. On entering the lens the rays are for the same reason—*i. e.*, the passage from a rarer into a denser medium—again refracted and converged, and if continued would come to a focus about 6.5 mm. behind the retina. On passing from the lens into the vitreous—*i. e.*, from a denser into a rarer medium—the rays are once more converged and to an extent sufficient to focalize them on the retina (Fig. 310).

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* Strictly speaking, the posterior surface of the cornea is not parallel to the anterior surface, and the index of refraction of the cornea is a trifle greater than that of the aqueous humor, viz., 1.377. But as the increase in the corneal refraction due to a higher index is almost exactly counteracted by a decrease in refraction, due to the higher curvature of the posterior corneal surface, the usual assumptions furnish quite accurate results.

While it is thus possible to geometricly follow the rays through these media by means of the above-mentioned factors, the procedure is attended with many difficulties. Moreover, as the relations all change when rays enter the eye from objects situated progressively nearer the eye, a separate calculation is necessitated for each distance for the determination of the size of the image.

A method by which these difficulties are much reduced was suggested by Gauss and developed by Listing. It was demonstrated by Gauss that in every complicated system of refracting media separated by centered spheric surfaces there may be assumed certain *ideal* or *cardinal points*, to which the system may be reduced, and which, if their relative position and properties be known, permit of the determination, either by calculation or geometric construction, of the path of the refracted ray, and the position and size of the image in the last medium, of the object in the first.

Every dioptric system can be replaced, as Gauss showed, by a single system composed of six cardinal points and six planes perpendicular to the common axis—*e. g.*, two focal points, two principal points, two nodal points, two focal planes, two principal planes, and two nodal planes.

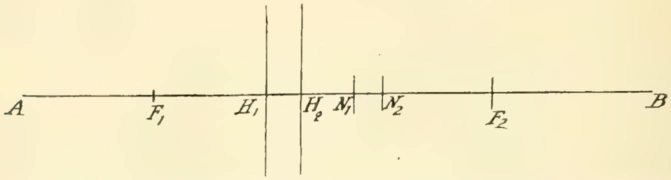

FIG. 311.—DIAGRAM SHOWING THE POSITION AND RELATION OF THE CARDINAL POINTS.

Properties of the Cardinal Points.—The *first focal point*, F_1, in Fig. 311, has the property that every ray which before refraction passes through it, after refraction is parallel to the axis.

The *second focal point*, F_2, has the property that every ray which before refraction is parallel to the axis, passes after refraction through it.

The *second principal point*, H_2, is the image of the *first*, H_1; that is, rays in the first medium which go through the first principal point pass after the last refraction through the second. Planes at right angles to the axis at these points are *principal planes*. The second principal plane is the image of the first. Every point in the first principal plane has its image after refraction at a corresponding point in the second principal plane at the same distance from the axis and on the same side.

The *second nodal point*, N_2, is the image of the *first*, N_1: a ray which in the first medium is directed to the first nodal point passes after refraction through the second nodal point, and the directions of the rays before and after refraction are parallel to each other. In

Fig. 311 let A B represent the axis. The distance of the first focal point, F_1, from the first principal plane, H_1, is the *anterior focal distance.* The distance of the posterior focal point, F_2, from the second principal plane, H_2, is the *posterior focal distance.* The distance of the first nodal point, N_1, from the first focal point is equal to the second focal distance. The distance of the second nodal point, N_2, from the posterior focal point is equal to the anterior focal distance. It is evident, therefore, that the distance of the corresponding principal and nodal points from each other is equal to the differences between the two focal distances. Also the distance of the two principal points from each other is equal to the distance of the two nodal points from each other. Finally, the focal distances are proportional to the refractive indices of the first and last media. Planes passing through the focal points vertically to the axis are known as *focal planes.*

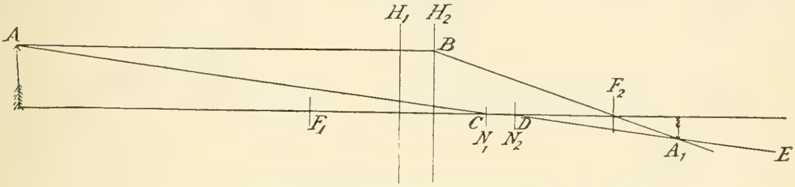

FIG. 312.—DIAGRAM TO FIND THE IMAGE IN LAST MEDIUM OF A LUMINOUS POINT IN THE FIRST.

From these properties of the cardinal points the position of an image in the last medium of a luminous point in the first may be determined, and the course of a refracted ray in the last medium be constructed if its direction in the first be given according to the following rules:

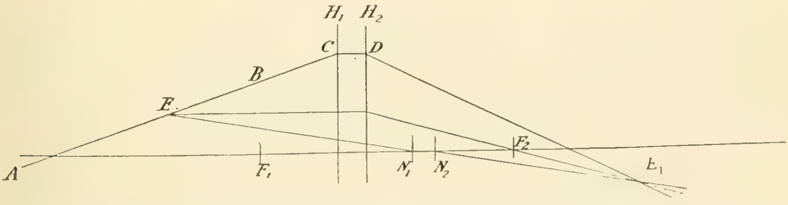

FIG. 313.—DIAGRAM TO FIND THE REFRACTED RAY IN THE LAST MEDIUM OF A GIVEN RAY IN THE FIRST MEDIUM.

1. To find the image in the last medium of a luminous point in the first: Let A (Fig. 312) be this given point. Draw A B parallel to the axis until it meets the second principal plane in B; then $B F_2$ will be this ray after refraction. Draw a second ray from A to the first nodal point; then draw another ray, D E, from the

second nodal point parallel to *A C*. This will be the refracted ray in the last medium. Where the two refracted rays, BF_2 and *D E*, intersect, the image of *A* will be A_1.*

2. To find the refracted ray in the last medium of a given ray in the first medium: Let *A B* (Fig. 313) be the given ray. Continue this ray until it meets the first principal plane in *C*. Draw *C D* parallel to the axis. Now assume any point, such as *E*, in the given ray, and find its image E_1 by the Rule 1. Then $D E_1$ becomes the course of the refracted ray.

The Schematic Eye.—Accepting the system of cardinal points,

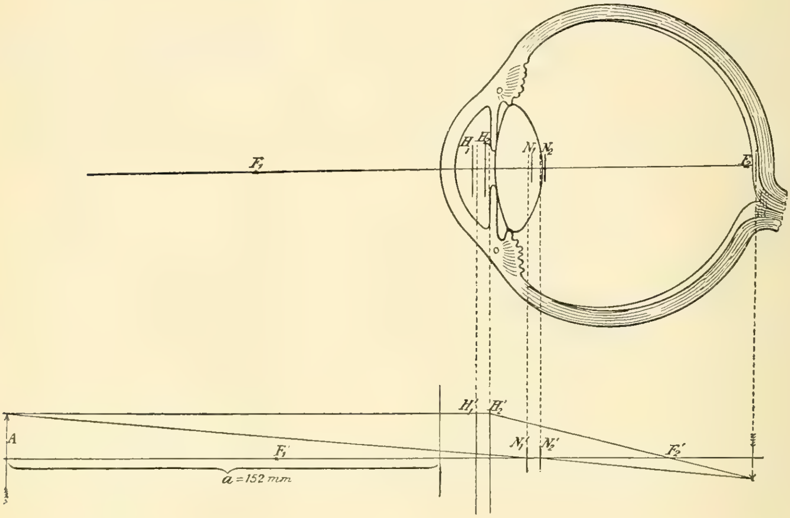

Fig. 314.—Diagram showing the Position of the Cardinal Points in the "Schematic Eye." The continuous lines in the upper half of the figure show their position in the passive emmetropic eye. The dotted lines indicate the change in their position in an eye accommodated for the object *A* at the distance *a* from the cornea, or 152 mm. The lower half of the figure shows the formation of a distinct image on the retina of an eye accommodated for the object *A* at the distance *a* from the cornea.

Listing, Donders, and v. Helmholtz have constructed "schematic" eyes to be substituted for the refracting system of the natural eye.

For this purpose it is necessary to make use of the various estimates of the indices of refraction of the different media, of the radii of curvatures of the different refracting surfaces, and of the distances separating them, to deduce an average eye as a basis for calculation. The most widely accepted attempt is that of v. Helmholtz. The data he assumed are as follows: The refractive index of air = 1; of the cornea and aqueous humor, 1.3365; of the lens, 1.4371; of the vitreous humor, 1.3365; the radius of curvature of the cornea, 7.829 mm.; of the anterior surface of the lens, 10 mm.; of the posterior surface, 6 mm.; the distance from the apex of the cornea to the anterior surface of the lens, 3.6 mm.; thickness of lens, 3.6 mm. From the above-mentioned data v. Helmholtz calculated the position of the cardinal points for the eye as follows (see Fig. 314): The first focal point is situated 13.745 mm. before the anterior surface of the cornea; the posterior focal point is situated 15.619 mm. behind the posterior surface of the lens; the first principal point, 1.753 mm. behind the cornea; the second principal point, 2.106 mm. behind the cornea; the first and second nodal points, 6.968 and 7.321 mm. behind the apex of the cornea, respectively. The anterior focal distance of this schematic eye, the distance between F_1 and H_1, therefore amounts to 15.498 mm., and the posterior focal distance, H_2 to F_2, to 20.713 mm.

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* If the point *A* is infinitely far from the eye, all the rays striking the eye will be parallel to each other. The nodal ray must therefore be drawn, and the point where this nodal ray meets the second focal plane will be the image of $A = A_1$ where all rays parallel to the nodal ray will meet.

When the eye, however, is accommodated for near vision, the relations of the cardinal points are changed and will be as follows, if the point accommodated for, lies 152 mm. from the cornea: Anterior focal distance, 13.990 mm.; posterior focal distance, 18.689 mm.; distance from cornea of the first and second principal points, 1.858 and 2.257 mm. respectively; distance of the posterior focus, 20.955 mm. from cornea. Given this schematic eye in the accommodated state, the course of the rays and the determination of the position of an image in the last medium of a luminous point in the first can easily be determined by the rules already given.

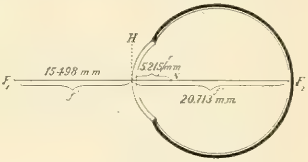

Fig. 315.—The Reduced Eye.

The Reduced Eye.—As suggested by Listing, this schematic eye may be yet further simplified or reduced to a single refracting surface bounded anteriorly by air and posteriorly only by aqueous or vitreous humor. Without introducing any noticeable error in the determination of the size of the retinal image, the anterior principal and the anterior nodal points may be disregarded, owing to the minuteness of the distances (0.39 mm.) separating the two systems of points. There is thus obtained one principal point and one nodal point, which latter becomes the center of curvature of the single refracting surface. The dimensions of this "reduced" eye are as follows (see Fig. 315). From the anterior surface of the cornea, corresponding to the principal plane H, to the nodal point N, 5.215 mm., from the anterior focal point F_1, to the principal plane H, *i. e.*, the anterior focal distance f', 15.498 mm.; from the principal plane H to the posterior focal point F_2, *i. e.*, the posterior focal distance f'', 20.713 mm.; the index of refraction is 1.3365. There is thus substituted for the natural eye a single refracting surface with a radius of curvature, r, of 5.215 mm. In such an eye luminous rays emanating from the anterior focal point are parallel to the axis after refraction in the interior of the eye.

Also rays parallel to the axis before refraction unite at the posterior focal point.

By means of this reduced eye the construction of the refracted ray, the various calculations as to the size of the image, the size of diffusion circles, etc., are greatly facilitated: *e. g.*,

In Fig. 316 let *A B* represent an object. From *A* homocentric rays fall on the single refracting surface. One of the rays, the nodal ray, falling on the surface perpendicularly, passes unrefracted through the single nodal point, *N*, to the posterior focal plane. The remaining rays, partially represented in the figure, falling on this surface under varying degrees of incidence, undergo corresponding degrees of refraction, by which they form a converging cone of rays which unite at a point situated on the nodal ray. These two points, *A*, *a*, are known as *conjugate foci*. The same holds true for homocentric rays emanating from *B* or any other point of the object.

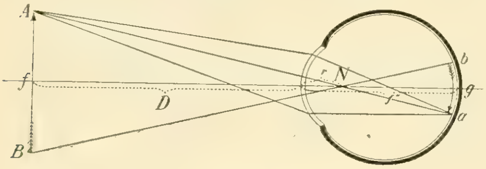

Fig. 316.—The Formation of an Image in the Reduced Eye.

The Size of the Retinal Image.—The size of the retinal image, *I* (in Fig. 316 *a b*), may now be easily calculated, when the size of the object, *O* (in Fig. 316 *A B*), and its distance, *D*, from the refracting surface with radius of curvature, r, are known, by the following formula:

$$O : I = D + r : f'' - r.$$

For, as the triangles *A N B* and *a N b* are similar, we have

$$A\,B : a\,b = f\,N : N\,g, \text{ or } a\,b = \frac{A\,B \times N\,g}{f\,N}.$$

Independent of the foregoing method, the size of the retinal image may be calculated if it is remembered that the eye, like any optic system, has a point of such a quality that a ray of light which before entering the eye was directed toward it, after refraction continues as if it came from this point. In other words, there is in the eye a point which allows a ray of light to pass unrefracted. This point, termed the nodal point of the eye, determines the size of the image; for if a line be drawn from both the upper and lower ends of an object through this nodal point, it is clear that the images of the respective points must lie on these two rays where they intersect the retina. The distance of this nodal point from the retina is 15.498 mm. It is clear, therefore, that the size of the object is to the size of the image, as the distance of the object from the nodal point is to the distance of the nodal point from the retina; or, in other words, to find the size of the retinal image: multiply the size of the object by 15.5 mm. and divide by the distance of the object from the eye.

The visual angle is defined as the angle formed by the intersection of two lines drawn from the extremities of an object to the nodal point of the eye. Beyond the nodal point, however, the lines again diverge and form an inverted or reversed image of the object on the retina. The size of the visual angle increases with the nearness and decreases with the remoteness of the object; the retinal image correspondingly increases and decreases in size. These facts will become apparent from an examination of Fig. 317. As the size of the retinal image diminishes as the visual angle diminishes either as a result of the removal of a given object from the eye, or of a diminution of the size of the object, there comes a limit in the size of the visual angle, beyond which it is impossible to see the two end points (A and B) of the object separately. When this limit is reached the size of the angle expressed in degrees of the circle, may be determined if the distance between the two points and their distance from the eye be known. Thus it has been experimentally determined that at a distance of 5 meters, the smallest object or the smallest interval between two points which permits the eye to distinguish them as such, is about 1.454 mm. Lines drawn from the extremities of such an object or interval, to the nodal point, subtend an angle of 60 seconds.* Beyond this the two points are indistinguishable. In other words the emmetropic eye possesses the power of distinguishing the correspondingly small interval between the two images on the retina of the two objective points. The size of the image or the interval between the two retinal points, determined from the foregoing factors by the formulæ on page 664 is 0.004 mm., and which would correspond

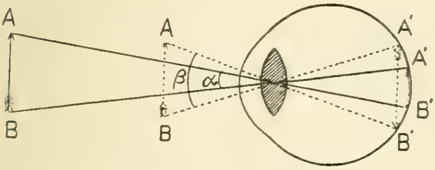

FIG. 317.—DRAWING DESIGNED TO SHOW HOW THE VISUAL ANGLE AND SIZE OF RETINAL IMAGE VARIES WITH THE DISTANCE OF AN OBJECT OF GIVEN SIZE. For the distant position of A–B the visual angle is *a*; for the near position (dotted lines) *β*. (*From Stewart.*)

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*The size of the visual angle, under which an object of this size and situated at a distance of 5 meters is distinctly seen, can be determined from the following Fig. 318, in which *A B*, represent the size of the object 1.454 mm.; *N*, the nodal point; *CN*, the line which bisects the object, represent the distance of the object from the nodal point; *a*, the visual angle subtended and whose value it is desired to know, and *b* one-half of the angle *a*. By trigonometry the size of the angle *a* can be determined in the following way: one-half the size of the object *A B*, is divided by its distance from the nodal point; the quotient is the tangent of half the angle. Thus 0.727 ÷ 5000 = 0.0001454. By reference to logarithmic tables it will be found that the angle or fraction of the circle corresponding to this tangent is 30 seconds, and that therefore the whole angle is 60 seconds.

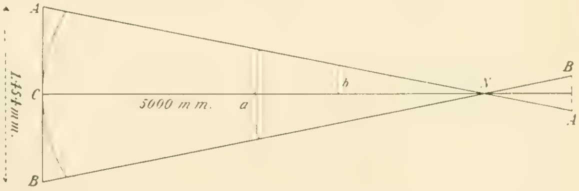

FIG. 318.—FIGURE SHOWING THE METHOD OF OBTAINING THE VISUAL ANGLE EXPRESSED IN DEGREES OR FRACTION OF A DEGREE OF THE CIRCLE.

to a visual angle of 60 seconds. If the retinal distance is less than this the two sensations fuse into one. The reason assigned for this is, that the distance between the centers of two adjoining cones in the macula is 0.004 mm. With a visual angle not less than 60 seconds, the two foci fall on separate cones. With a smaller visual angle the two foci fall on, and excite but a single cone and hence there arises the sensation of but a single point. The acuteness of vision, therefore, of the emmetropic eye depends on its power of distinguishing the smallest retinal image or the smallest interval between two points on the retina corresponding to a visual angle of 60 seconds.

In ophthalmic practice it is customary in testing the acuteness of vision to employ test letters of specific sizes for specific distances. The letters are so proportioned that when they are placed at the specified distances, the extremities of the letters subtend an angle of 5 minutes. The letters have been constructed on the following basis: Since to an angle of 60 seconds there corresponds an object of 1.454 mm. at the distance of 5 meters as shown before and as the object decreases in proportion to the distance (for the same visual angle) it is evident that the object would have to be one-fifth of 1.454 mm. or 0.2908 mm. in order to subtend an angle of 60 seconds at one meter. From this the size for any other distance in meters is found simply by multiplying 0.2908 mm. with the distance.

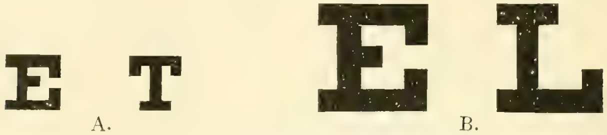

FIG. 319.—STANDARD TEST LETTERS.

The standard letters are so constructed that each meridian is composed of five squares, each of which at a specified distance, subtends an angle of 1 minute, and hence the entire letter an angle of 5 minutes. The letter that could be distinctly seen at a distance of 5 meters, would have, therefore, a vertical and a horizontal meridian of 5 times 1.454 mm. or 7.27 mm. (Fig. 319 A), and at 10 meters corresponding meridians of 14.54 mm., etc. (Fig. 319 B.)

If with the accommodation suspended, the emmetropic eye could clearly distinguish a letter 7.27 mm. in size at a distance of 5 meters and which would, therefore, subtend an angle of 5 minutes, the acuity of the vision would be normal and could be expressed as follows: $V=\frac{5}{5}$ or $V=1$. If on the contrary at this distance the smallest letter that could be clearly seen is one that subtends an angle of 5 minutes at a distance of 10 meters then the visual acuity would be only one-half the normal and could be expressed as follows $V=\frac{5}{10}$ or $V=\frac{1}{2}$, etc. The acuity of vision is expressed, therefore, by a fraction the enumerator of which is the distance at which the test is made, and whose denominator is the distance at which the smallest letters distinguished by the patient, subtend an angle of 5 minutes, but which in the instance cited above subtends an angle of 10 minutes; or in other words the distance at which the patient reads divided by the distance at which he ought to read the smallest letters seen by him were his visual acuity normal.

Accommodation.—Accommodation may be defined as the power which the eye possesses of adjusting itself to vision at different distances; or in other words, the power of focusing rays of light on the retina, which come from different distances at different times. That such a power is a necessity is apparent from the fact that it can not focus rays coming from a distant and a near object at the same time. Thus, if an object is held before the eye at a distance of 22 centimeters, for example, and the vision is directed to a distant object it is evident that the near object is indistinctly seen; but if the vision is then directed to the near object, it in turn becomes clear and distinct, while the distant object becomes blurred and indistinct. It is evident, therefore, that rays of light coming from a distant and a near object can not be simultaneously, but only alternately, focused on the retina. The observer at the same time becomes conscious, as the vision is directed from the distant to the near object, of a change in the eye itself, a change that involves time and effort. The reasons for these facts will become apparent from a consideration of the following facts:

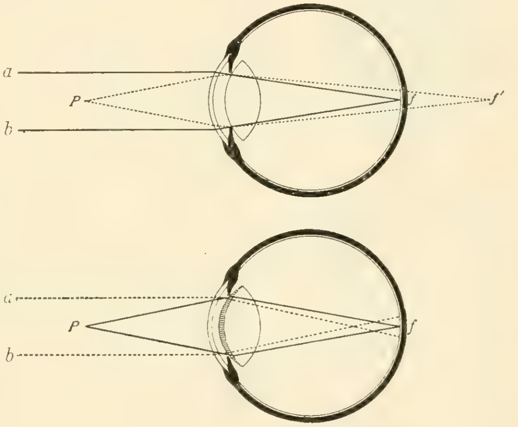

FIG. 320.—THE REFRACTION OF PARALLEL AND DIVERGENT RAYS IN THE EMMETROPIC EYE IN THE PASSIVE AND IN THE ACTIVE OR ACCOMMODATED CONDITION.

In a normal or *emmetropic* eye, homocentric parallel rays of light (Fig. 320, *a*, *b*) after passing through the optic media are converged and brought to a focus on the retina, *f*. Rays, however, which come from a luminous point situated near the eye, *P*, and are therefore divergent, passing through the optic media at the same time, are intercepted by the retina before they are focused, and give rise to the formation of *diffusion-circles* and indistinctness of vision. The reverse is also true. When the eye is adjusted for the refraction and focusing of divergent rays (Fig. 320, *P*) parallel rays will be brought to a focus before reaching the retina, and, again diverging, will form diffusion-circles. It is evident, therefore, that it is impossible to simultaneously focus both parallel and divergent rays, and to see distinctly at the same time, two objects which are situated at different distances. The eye must be alternately adjusted first to one object and then to another. To this adjustment the term accommodation has been given.

The following table of Listing shows the size of the diffusion-circles formed of objects situated at different distances when the accommodative power is suspended in an emmetropic eye:

Distance of Luminous Point.	Distance of the Focal Point behind the Posterior Surface of the Retina.	Diameter of the Diffusion-circle.
∞	0.0 mm.	0.0 mm.
65 m.	0.005 "	0.0011 "
25 "	0.012 "	0.0027 "
12 "	0.025 "	0.0056 "
6 "	0.050 "	0.0112 "
3 "	0.100 "	0.0222 "
1.500 "	0.20 "	0.0443 "
0.750 "	0.40 "	0.0825 "
0.375 "	0.80 "	0.1616 "
0.188 "	1.60 "	0.3122 "
0.094 "	3.20 "	0.5768 "
0.088 "	3.42 "	0.6484 "

The normal eye when adjusted for distant vision is in a passive condition, and hence vision of distant objects is unattended with fatigue. In the act of adjustment, however, for near vision the eye passes into an active state, the result of a muscle effort, the energy of which is proportional to the nearness of the object toward which the eye is directed.

From the foregoing table it is evident that between infinity and 65 meters, the diffusion-circles are so slight that no perceptible accommodative effort is required to eliminate them. From 65 meters to 6 meters the diffusion-circles gradually become larger, though they are yet so faint as to require for their correction an accommodative effort which is scarcely measurable. From 6 meters up to 6 centimeters, however, a progressive increase in accommodative power is demanded for distinct vision.

Mechanism of Accommodation.—Inasmuch as neither the corneal curvature nor the shape of the eyeball undergoes any change during accommodation, the necessary change, whatever it may be, is to be sought for in the lens. As to the character of the changes in this body, two views are held, based largely on the fact and its interpretation, that images of a luminous point reflected from the anterior surface of the cornea, the anterior and posterior surfaces of the lens, change their relative positions during accommodation.

Thus, if in a darkened room a lighted candle be placed in front of and to the side of an individual whose eye is directed to a distant object, an observer placed in the same relative position as the candle will observe three images in the eye, one at the surface of the cornea, two at the pupillary margin (Fig. 321). Of the two latter, one is quite large and situated apparently in front of the third, which is faint, small, and inverted. The middle image is reflected from the convex surface of the lens, the last from the concave surface. These images of reflection are known as *catoptric* images. If now the individual be directed to fix the gaze on a near object, the second image changes its position, advances toward the corneal image and at the same time becomes smaller, a change which, in accordance with the laws of optics, could only be due to an increase in the convexity of the anterior surface of the lens. A slight displacement of the third image sometimes observed indicates a possible increase in the convexity of the posterior surface lens.

According to Helmholtz, during accommodation the entire anterior surface of the lens becomes more convex, while at the same time it slightly advances, possibly as much as 0.4 mm. in extreme efforts. This change is represented in Fig. 322. According to Tscherning, the increase in convexity of the anterior surface is confined to the central portion, the remainder of the surface becoming somewhat flattened. There is, moreover, no evidence that there is any advance of the surface or any increase in the thickness of the lens. A series of new and ingenious experiments lend support to Tscherning's view. The radius of curvature in either case approximates 6 mm. in extreme efforts of accommodation. The increase in convexity naturally increases the refracting power.

Whichever view is accepted, the nearer the object—that is, the greater the degree of divergence of the light rays—the more pronounced must be the increase in convexity in order that they may be sufficiently converged and focalized on the retinal surface. Changes in the convexity of the lens, either of increase or decrease, are attended by changes in the distinctness of images. Coincident with the lens change, the pupillary margin advances and the pupil itself becomes smaller. By this means an indistinctness of the image is prevented by cutting off the rays which would give rise, owing to the angle at which they fall on the surface, to diffusion-circles, from spheric aberration.

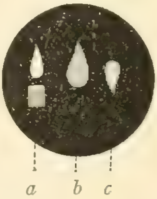

FIG. 321.—CATOPTRIC IMAGES IN THE EYE. *a.* Upright image of reflection, from the cornea. *b.* Upright image from the anterior surface of the lens. *c.* Inverted image, from the posterior surface of the lens.—(*Helmholtz.*)

The Function of the Ciliary Muscle.—Though it is generally admitted that the increase in the convexity of the lens is caused by the contraction of the ciliary muscle, the exact manner in which this is accomplished is not clearly understood. According to Helmholtz, when the eye is in repose and directed to a distant object the lens is somewhat flattened from a traction exerted by the suspensory ligament. When the eye is directed to a near object, the ciliary muscle contracts, thereby relaxing the ligament, as a result of which the lens, by virtue of an inherent elasticity, bulges forward and becomes more convex. In consequence of this latter fact the refracting power is proportionally increased. In extreme efforts of accommodation it is believed by some observers that the circularly arranged fibers, the so-called annular muscle, contract and exert a pressure on the periphery of the lens and thus aid other mechanisms in relaxing the ligament and in increasing the convexity. This view appears to be supported by the fact that in hypermetropia, where a constant effort is required to obtain a distinct image of even distant objects, the annular muscle becomes very much hypertrophied, thus reinforcing the meridional fibers. In myopia, on the contrary, where the accommodative effort is at a minimum, the entire muscle possesses less than its average size and development.

According to Tscherning, a different explanation of the action of the ciliary muscle must be given. Thus, when it contracts, the antero-internal angle, that portion in close relation with the suspensory ligament, recedes and exerts on the ligament a pressure which in turn exerts a traction on the peripheral portions of the anterior surface of the lens, which produces the deformation observed. At the same time the postero-external portion of the muscle exerts traction on the chorioid, thus sustaining the vitreous and indirectly the lens.

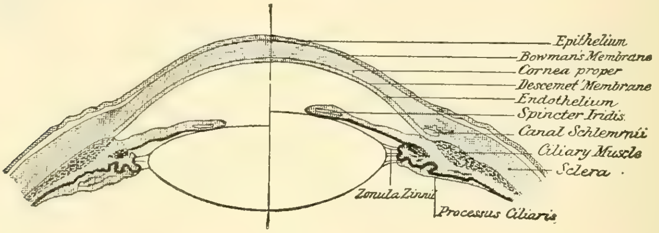

FIG. 322.—THE LEFT HALF REPRESENTS THE EYE IN A STATE OF REST. THE RIGHT HALF IN STATE OF ACCOMMODATION.

The reason for the flattening of the periphery of the lens from zonular compression and the sharpening of the central convexity is to be found in the fact that the convexity of the more solid central portion, the nucleus, is greater than that of the lens itself. Hence it is easily understood why a zonular traction would give rise to peripheral flattening.

There is, however, one point which seems difficult to harmonize with Tscherning's view; that is, the fact that during accommodation the lens appears to be slightly tremulous, thus showing relaxation, and not increased tension, of the suspensory ligament.

Range of Accommodation.—It has been stated that rays of light coming from a luminous point situated at any distance beyond 65 meters are so nearly parallel that no accommodative effort is required for their focalization. So long as the luminous point remains between infinity and 65 meters, the eye, directed toward it, remains completely relaxed. The point at which the object can be distinctly seen without accommodation is termed the far point or the *punctum remotum*. This for the normal eye is at a distance of 65 meters or beyond.* If the luminous point gradually approaches the eye from a point 65 meters distant, the accommodative power comes into play and gradually increases until it attains its maximum. The nearest point up to which the eye is able to form distinct images of objects is called its near point or punctum proximum. This near point in a healthy boy of twelve years will lie at 2⅔ inches from the eye, while the same point lies only at 8 inches or 20 cm. in a man of forty years. Of objects which lie nearer than the punctum proximum the eye cannot form distinct images. The distance between the *punctum remotum* and the *punctum proximum* is termed the *range of accommodation.*

Force of Accommodation.—The increase in curvature of the lens necessary to focalize rays when the eye is directed from the far to the near point necessitates the expenditure of energy on the part of the ciliary muscle. The energy expended in the act of accommodation may be measured by a lens, the refracting power of which is such as to enable it to produce the same result—that is, to give the diverging rays coming from the near point, *e. g.*, 20 cm., a parallel direction. A lens, therefore, which has for a near point a focal distance of 20 cm. would be a measure of the force expended, for such a lens placed in front of the *crystalline* lens, when in a state of repose, would, with the assistance of the latter, bring diverging rays coming from the near point to a focus on the retina. A lens of this character is said to have a refracting power of 5 dioptries.

Since lenses of the same curvature made from different materials have different refracting powers, it becomes necessary to have, for purposes of comparison, some unit of measurement. The unit now accepted is the refracting power of a glass lens which is sufficient to focalize parallel rays at a distance of 100 cm. or 1 meter. This amount of refracting power is termed a dioptry. Lenses which would focalize parallel rays at a distance of 50, 20, or 10 cm. are said to have a refractive power of 2, 5, or 10 dioptries, respectively, obtained by dividing into 100 cm. the focal distance. The refracting power of a biconcave lens is determined by prolonging backward in the direction the parallel rays have come, the rays which have been rendered divergent by the lens.

The refracting media of the human eye in *repose* have collectively a refracting power of about 64 dioptries, the reciprocal of its focal length. The refracting power of the corneal surface alone is equivalent to 42 dioptries. The crystalline lens could in the schematic eye be replaced by a lens of about 13 dioptries in front of the eye, as is done after the extraction of a cataract. But owing to its position in a medium denser than air, it has been calculated that its refracting power is about 20 dioptries.

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* In practical ophthalmic work a point six meters distant is taken as the far point for the reason that the rays at this distance are practically parallel.

The capability of the lens to increase its refraction during accommodative efforts beyond the 20 dioptries varies considerably at different periods of life. At ten years the increase is 14 dioptries, as the near point is 7 cm.; at thirty years the increase is but 7 dioptries, as the near point is 14 cm.; at sixty the increase is but 1 dioptry and the near point 100 cm.; at seventy it is zero. From youth to old age, the elasticity of the lens steadily declines, and the range of accommodation diminishes from the recession of the near point.

Convergence of the Eyes during Accommodation.—In binocular vision of near objects the eyes are turned inward and the optic axis of each—a line passing through the center of the cornea and the center of the eye—turned toward the median line during accommodation. So long as the eyes are directed toward the far point, 65 meters or beyond, the optic axes are parallel. When the eyes are directed to any point within 65 meters the optic axes are converged, the convergence increasing steadily as the near point is approached. In this way the fovea of each eye is directed to the same point and single vision made possible. Were this not the case, double vision would result.

Functions of the Iris.—For purposes of distinct vision it is essential that the quantity of light entering the interior of the eye shall be so adjusted that the formation and subsequent perception of the image shall be sharp and distinct. This is accomplished by the iris, the circular fibers of which alternately contract and relax with increasing and decreasing intensities of the light. The size of the pupil, therefore, through which the light passes, will vary from moment to moment and in accordance with variation in the light intensity. The quantity of light necessary to distinct vision is thus regulated.

In the total absence of light the sphincter pupillæ muscle is relaxed and the pupil widely dilated. With the appearance of light and an increase in its intensity the muscle again contracts and the pupil progressively narrows. With a given intensity in the light, the sphincter contraction is greater when the light falls directly into the fovea. Contraction of this muscle also occurs as an associated movement in the convergence of the eyes during accommodation and in consensus with the other eye.

In addition to this function of the iris, it constitutes, by virtue of the sphincter muscle contraction, an important corrective apparatus. Being non-transparent, it serves as a diaphragm intercepting those rays which would otherwise pass through the peripheral portions of the lens and by spheric aberration give rise to indistinctness of the image. The movements of the iris by which the size of the pupil is determined are caused by the contractions and relaxations of the *sphincter pupillæ* and *dilatator pupillæ* muscles. The contraction of the sphincter is entirely reflex and involves those structures necessary to the performance of any reflex act, viz.: a receptive surface, the retina; afferent nerves, the pupillary fibers of the optic nerve; a central emissive center situated in the gray matter beneath the aqueduct of Sylvius; and efferent nerves, the motor oculi and the ciliary nerves. The stimulus requisite to the excitation of this mechanism is the impact of light waves or ether vibrations on the rods and cones. According to the intensity of these vibrations will be the resulting contraction of the muscle. The contraction of the dilatator pupillæ muscle is determined by the activity of a continuously active nerve-center in the medulla oblongata which transmits its nerve impulses through the spinal cord, along the first and second dorsal nerves to the superior cervical ganglion, and thence to the iris by way of the fifth nerve. (See Fig. 272, page 589.) These two muscles appear to bear an antagonistic relation to each other, for section of the motor oculi is followed by relaxation of the sphincter muscle and dilatation of the pupil. Stimulation of the sympathetic is followed by a more pronounced dilatation. The size of the pupil is the resultant of a balancing of these two forces.

OPTIC DEFECTS.

Presbyopia.—This is a condition of the eye characterized by a defective or diminished accommodative power. As age advances the lens loses its elasticity and the power to increase its refraction, and vision at the normal reading distance becomes impossible. The near point, therefore, advances toward the far point, or recedes from the individual. The range of accommodation is also diminished. At forty years the near point is about 22 cm.; at forty-five years it has receded to 28 cm. This would indicate that the lens in these five years has lost 1 dioptry of refracting power; at fifty years the near point recedes to 43 cm., and at sixty to 200 cm., indicating a loss in refracting power on the part of the lens of 2 and 4 dioptries respectively. Convex lenses placed before the eyes having a refracting power of 1, 2, and 4 dioptries would in the three instances return the near point to its normal position. At the age of seventy the lens is incapable of any increase during an accommodative effort. A lens of 4 dioptries would therefore be required by such a man, for near vision at 10 inches.

Myopia.—This is a condition of the eye characterized by an increase in the antero-posterior diameter or a hypernormal refracting power of the lens. The former is the usual condition. Parallel rays of light brought to a focus in front of the retina again diverge, giving rise to diffusion-circles and indistinctness of the image. Divergent rays alone are capable of being focalized on the retina in its new position. The punctum remotum is always at a definite distance, but approaches the eye as the myopia increases. The near point is usually much nearer the eye than 20 cm. For this reason the condition is termed *near sight.* (Fig. 323.)

The increase in the length of the antero-posterior diameter may range from a fraction of a millimeter up to 10 mm. With an increase of 0.16 mm. the far point is but 200 cm. distant; and with an increase of 3.2 mm. it is but 10 cm. distant. Inasmuch as only divergent rays can be focalized by the myopic eye normal vision can be restored by the use of a biconcave lens with a diverging power in the first instance of 0.5 dioptry and the second of 10 dioptries. (Fig. 324.)

Hypermetropia.—This is a condition of the eye characterized by decrease of the normal antero-posterior diameter or by a subnormal refracting power of the lens. The former is the usual condition.

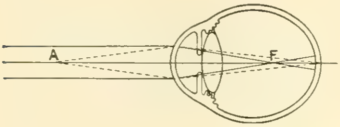

FIG. 323.—MYOPIA. Parallel rays focus at F, cross and form diffusion-circles; divergent rays from A focus on the retina.—(*Hansell and Sweet.*)

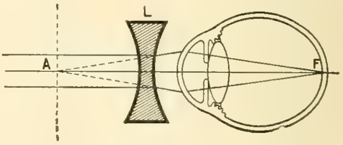

FIG. 324.—CORRECTION OF MYOPIA BY A CONCAVE LENS.—(*Hansell and Sweet.*)

Parallel rays of light do not, therefore, come to a focus when the accommodation is suspended. Falling on the retina previous to focalization, they give rise to diffusion-circles and indistinctness of the image. As no object can be seen distinctly no matter how remote, there is no *positive* far point. The near point is abnormally distant—sometimes as far as 200 cm. For this reason the condition is termed *far sight.* A hypermetropic eye without accommodative effort can focalize only converging rays on the retina. If rays of light were to come from the retina of such an eye, they would, on emerging, take a divergent direction, as shown in Fig. 325, dotted line *C* and *D.* If these same rays were to be prolonged backward, they would meet at the point *K*, which is the *punctum remotum;* and as it is behind the eye, it is termed *negative.* Since rays coming from the retina take a divergent direction on emerging from the eye, it is evident that only converging rays can be focalized by a passive hypermetropic eye. As there are no convergent rays in nature, it is necessary for distinct vision that all rays, parallel and divergent, shall be given

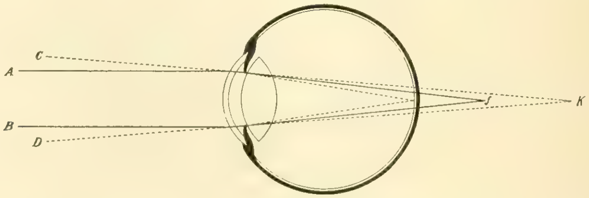

FIG. 325.—THE HYPERMETROPIC EYE. Parallel rays (*A*, *B*) can be focused only at a point behind the eye, as at *f*; rays of light coming from the retina take, on emerging from the eye, a divergent direction, *C*, *D*. *K*. The negative punctum remotum.

a convergent direction before entering the eye. This is done by placing before the eye convex lenses the converging power of which is proportional to the degree of hypermetropia (Figs. 326, 327).

Astigmatism.—This is a condition of the eye characterized by an inequality of curvature of its refracting surfaces in consequence of which not all of a homocentric bundle of rays are brought to the same focus. The inequality may be either in the cornea or lens, or both, though usually in the cornea.

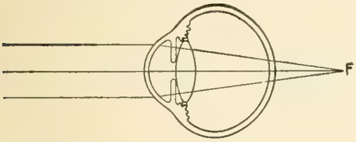

Fig. 326.—Hypermetropia. Parallel Rays Focused behind the Retina.—(*Hansell and Sweet.*)

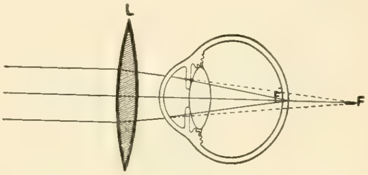

Fig. 327.—Correction of Hypermetropia by a Convex Lens.—(*Hansell and Sweet.*)

In the normal cornea the radius of curvature in the vertical meridian is a trifle shorter, 7.6 mm., than that of the horizontal, 7.8 mm., and hence its focal distance is slightly shorter. The difference, however, in the focal distances is so slight that the error in the formation of the image is scarcely noticeable. A transection of a cone of light coming from the cornea is practically a circle. If, however, the vertical curvature exceeds the normal to any marked extent, the rays passing through this meridian will be more sharply refracted and brought to a focus much sooner than the rays passing through the horizontal meridian. The result will be that the cone of light will be no longer circular, but more or less elliptic. The variations of the shape of this cone are shown in Fig. 328, which represents the appearances presented on cross-section both before and after focalization of each set of rays. Though the vertical meridian has usually the sharper curvature, it not infrequently happens that the reverse is true. For the reason that the rays from one point do not all come to the same focus or point, the condition is termed astigmatism.

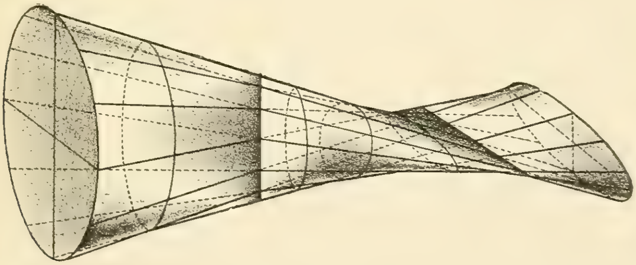

Fig. 328.—Refraction by an Astigmatic Surface.—(*Hansell and Sweet.*)

Spheric Aberration.—When the rays of light which emanate from a point fall upon a spheric lens, they do not after passing through it reunite at one point because of the fact that the more peripheral rays have a shorter focus than the central rays. To this condition the term spheric aberration is given. Spheric aberration can be demonstrated in the human eye. That this condition is present to but a slight extent in the normal eye is due to the presence of the iris, which intercepts those rays which would otherwise pass through the marginal portions of the refracting media. In widely dilated eyes the spheric aberration of the peripheral parts may amount to as much as 4.5 dioptries.

Chromatic Aberration.—When a beam of white light is made to pass through a prism, it is decomposed into the primary colors owing to a difference in the refrangibility of the rays. In passing through the refracting media of the eye the different rays composing white light also undergo unequal refraction and those rays which give rise to one color are brought to a focus at a point somewhat different from those which give rise to other colors. If the eye is accommodated for one set of rays, it is not for another, and the result is a fringe of colors around the image. This defect in the normal eye is so slight that the mind fails to take cognizance of it. That the eye is incapable of simultaneously focalizing rays of widely different refrangibility, as those which give rise to the blue and red colors, is shown by the following experiment: The eye being directed to a luminous point, a plate of cobalt-glass is placed between the light and the observer close to the eye. This substance has the property of intercepting all rays but the red and the blue and hence these alone will be seen. The center of the image produced will be red and clearly defined, the periphery blue and ill defined. The reason for this is clear. The eye more readily accommodates itself for the red rays, and hence their focal point is distinct. The blue rays, having a higher degree of refrangibility, come to a focus, cross and diverge, and give rise to diffusion-circles. If a biconcave glass be placed before the cobalt, the blue rays can be focalized on the retina, while the red will fall on the retina without focalization. The image will now be blue and distinct in the center, the periphery red and ill defined. With the removal of the minus glass the reverse condition again obtains.

Imperfect Centering.—From a purely physical point of view, the eye is not a perfect optic instrument. In addition to the defects noticed in the foregoing paragraphs, there is yet another, viz.: an imperfect centering of the refracting surfaces. In first-class optic instruments the lenses are centered—that is, their exact centers are situated on the same axis. In viewing an object through such a system the visual line corresponds with the axis of the lens system. This is not the case with the refracting system of the eye. A line passing through the center of the cornea and the center of the eye, the *optic axis* (*O A* in Fig. 329), does not pass exactly through the center of the lens and does not fall into the point for most distinct vision, the fovea. This has led to the recognition of other lines the relations of which must be kept in mind in all optic discussions, viz.:

1. The *visual axis* or *visual line* (*V L*), the line connecting the point viewed, the nodal point and the fovea centralis.
2. The *line of fixation* or *line of regard* (*V C*), the line connecting the point viewed with the center of rotation, the latter being situated 6 mm. behind the nodal point of the eye and 9 mm. before the retina. The relation of these lines and certain angles connected with them are shown in Fig. 329. The angle included between the line *D D* (the major axis of the corneal ellipse) and the visual line is the angle *alpha*, amounting on the average to 5°. The angle included between the optic axis and the line of fixation or regard is the angle *gamma*, while the angle between the optic axis and the line of vision is the angle *beta*. In emmetropia the angle *alpha* is about 5°. In hypermetropia it is greater, amounting to 7° or 8°, giving to the eye an appearance of divergence. In myopia it is much smaller—2°—or in extreme cases may be abolished, the line of vision corresponding with the optic axis or even passing beyond it. The angle *gamma* is of value in determining the actual deviation of the eye in squint.

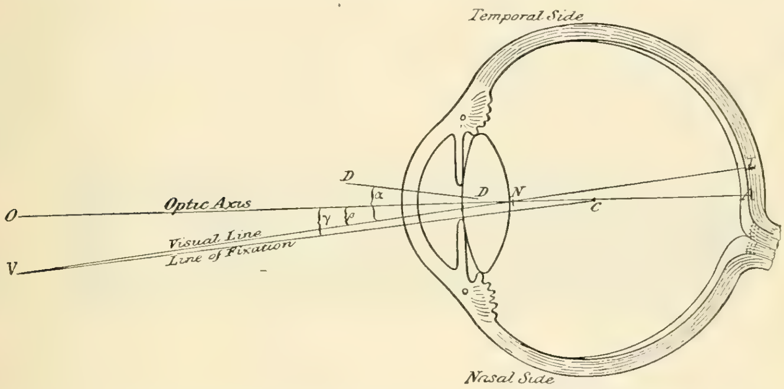

FIG. 329.—DIAGRAM SHOWING THE CORNEAL AXIS *D D*, THE OPTIC AXIS *O A*, THE VISUAL AXIS *V L*, AND THE LINE OF FIXATION *V C;* ALSO THE THREE ADGELS, α, β, γ,

Functions of the Retina.—Of all the layers of the retina, the rods and cones appear to be the most essential to vision. It is only this layer that is capable of receiving the light stimulus and of transforming it into some specific form of energy, which in turn arouses in the fibers of the optic nerve the characteristic nerve impulses. A ray of light entering the eye passes entirely through the various layers of the retina, and is arrested only upon reaching the pigmentary epithelium in which the rods and cones are embedded. As to the manner in which the objective stimuli—light and color, so called—

are transformed into nerve impulses, but little is known. It is probable that the ether vibrations are transformed into heat, which excites the rods and cones. These, acting as highly specialized end-organs of the optic nerve, start the impulses on their way to the brain, where the seeing process takes place. As to the relative function of the rods and cones, it has been suggested, from the study of the facts of comparative anatomy, that the rods are impressed only by differences in the intensity of light, while the cones, in addition, are impressed by qualitative differences in color. The nerve-fibers themselves are insensible to the impact of the ether vibrations, and require for their excitation some intermediate form of energy. That this is the case was shown by Donders, who reflected a beam of light on the optic nerve at its entrance without the individual experiencing any sensation of light. This region, occupied only by the optic-nerve fibers and devoid of any special retinal elements, is therefore an insensitive or *blind spot*. The diameter of this spot is about 1.5 mm., and occupies in the field of vision a space of about 6°. It is situated about 3.5 mm. to the nasal side of the visual axis. Its existence can be demonstrated by the familiar experiment of Mariotte, which consists in placing before the eye two objects having the relation to each other as in Fig. 330. With the left eye closed and the right eye directed to the cross, both objects may be visible. But by moving the figure away from or toward the eye, there will be found a distance, about 30 cm., when the circle will be invisible. This occurs when the image falls on the optic nerve at its entrance. The experiment of Purkinje as described in the following paragraph demonstrates also the fact that the sensitive portion of the retina is to be found only in the layer of rods and cones.

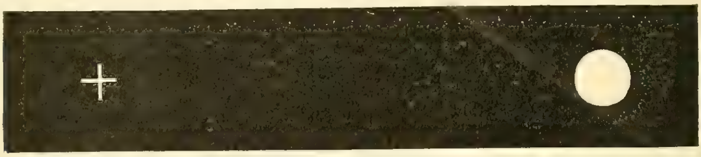

FIG. 330.—DIAGRAM FOR OBSERVING THE SITUATION OF THE BLIND SPOT.—(*Helmholtz.*)

It is well known that the blood-vessels of the retina are situated in its innermost layers a short distance behind the optic-nerve fibers. Owing to this anatomic arrangement, a portion of the light coming through the pupil will be intercepted by the vessels and a shadow projected on the layer of rods and cones. Ordinarily, these shadows are not perceived, for the reason that the shaded parts are more sensitive, so that the small amount of light passing through the vessels produces as strong an impression on this part as does the full amount of light on the unshaded parts of the retina, and perhaps because the mind has learned to disregard them. But if light be made to enter the eye obliquely, the position of the shadows will be changed, when at once they become apparent. This can be shown in the following way: If in a darkened room a lighted candle be held several inches to the side and to the front of the eye, and then moved up and down, there will be perceived, apparently in the field of vision, an arborescent figure corresponding to the retinal blood-vessels. This is due to the falling of the shadows on unusual portions of the layer of rods and cones.

Excitability of the Retina.—The retina is not equally excitable in all parts of its extent. The maximum degree of sensibility is found in the macula lutea, and especially in its central portion, the fovea. In this region the layers of the retina almost entirely disappear, the layer of rods and cones alone remaining, and in the fovea only the latter are present. That this area is the *point of most distinct vision* is shown by the observation that when the eye is directed to any given point of light, its image always falls in the fovea. Any pathologic change in the fovea is attended by marked indistinctness of vision. The sensibility of the retina gradually but irregularly diminishes from the macula toward the periphery. This diminution in sensibility holds true for monochromatic as well as white light.

As stated above, the nature of the molecular processes which take place in the retinal tissue, caused on one hand by the light vibrations, and on the other hand developing nerve impulses, is entirely unknown. The discovery of the *visual purple* in the outer segment of the rods gave promise of some explanation of the process, especially when it was shown to undergo changes when exposed to the action of light. But as the pigment is wanting in the cones, and especially in the fovea, it cannot be considered essential to distinct vision, although that it plays some important rôle in the visual process is highly probable. It was observed by Van Genderen Stort, that when an animal is kept in darkness some time before death, the cones are long and filiform; but if the animal has been exposed to light, they are short and swollen. It was discovered by Boll that if an animal is kept in darkness an hour or two before death the pigment is massed at the ends of the rods and cones, but after exposure to light it becomes displaced and extends over and between the rods almost to the external limiting membrane. These conditions are represented in Fig. 331.

The Eye a Living Camera.—In its construction, in the arrangement of its various parts, and in their mode of action the eye may be compared to a *camera obscura*. Though the comparison may not be absolutely exact, yet in a general way it is true that there are many striking points of similarity between them; *e. g.*, the sclera and chorioid may be compared to the walls of the camera; the combined refracting media to the single lens, the action of which results in the focusing of the light rays; the retina to the sensitive plate receiving the image formed at the focal point; the iris to the diaphragm for the regulation of the amount of light to be admitted, and for the partial exclusion of those marginal rays which give rise to *spheric aberration;* the ciliary muscle to the adjusting screw, by means of which the image is brought to a focus on the sensitive plate, notwithstanding the varying distances of the object from the lens. The presence of the *visual purple* in the rods of the retina capable of being altered by light makes the comparison still more striking.

Kühne even succeeded in obtaining a fixed image or an *optogram* of an external object in a manner similar to that by which an image is fixed on the sensitive plate of a camera. An animal is kept in the dark for about ten minutes in order to permit the retinal pigment to be completely regenerated. The animal, with the eyes covered, is then brought into a room with a single window. While the head is steadily directed to the window, the eye is exposed for several minutes. The eyes are again covered, the animal killed, and the eyes removed by the light of a sodium flame. The retina is then placed in a 4 per cent. solution of alum. In a short time the image of the window, the *optogram*, will be fixed (Fig. 332). That portion of the retina corresponding to the image is quite bleached in appearance from the action of the light on the pigment. During life the regeneration of the visual purple must take place with extreme rapidity. It is believed to be derived from a pigment secreted by the layer of pigment cells.

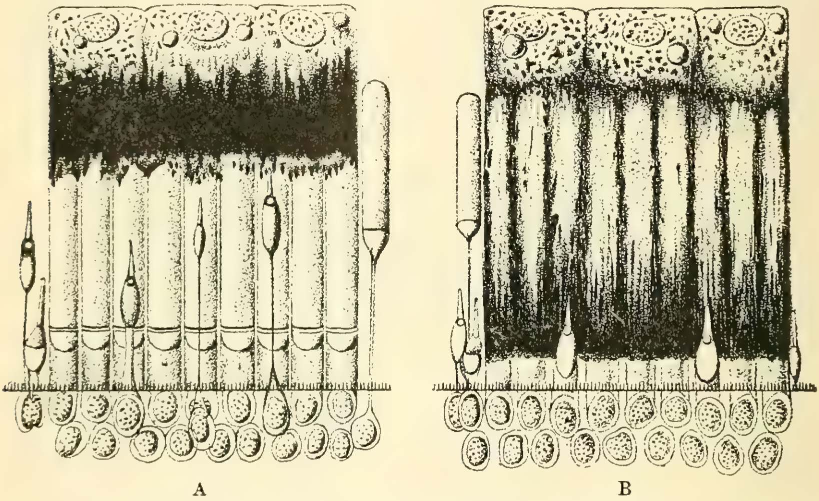

Fig. 331.—Section of the Retina of a Frog. A. In darkness. B. In light.—(*After Van Genderen Stort, from Tscherning's "Physiologic Optics."*)

Binocular Vision.—Though two images are formed, one on each retina, when the eyes are directed to a given object, there results but one sensation. If the direction of either visual axis be changed by pressure on the eyeball, there arise two sensations, and the object appears to be doubled. The reason assigned for this, in the first instance, is that the two images fall into the foveæ, two corresponding points; while in the second instance they fall on non-corresponding points. It would appear, therefore, that for the purpose of seeing an object singly when the eyes are directed toward it, the rays emanating from it must fall on corresponding parts of the retina. As all portions of the retina are sensitive to light, though in varying degrees, it is not essential that the images always fall in the foveæ. The parts of the retinæ which correspond physiologicly are shown in Fig. 333. In this figure the retinal area is divided into quadrants by vertical and horizontal lines of separation, as they are termed. If one retina is placed in front of or over the other, it will be found that the quadrants bearing similar letters cover each other. So long as the rays of light, entering the eye, fall on corresponding areas the sensation of but one object arises. If, however, they fall on non-corresponding areas, two sensations arise. Normal binocular vision enlarges very considerably the area of the visual field, permits of a better estimation of the size and distance of objects, enables the mind to form more readily a perception of depth, increases the intensity of sensations and makes sensation more uniform by off-setting retinal rivalry.

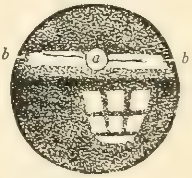

FIG. 332.—RETINA OF a RABBIT. OPTOGRAM OF A WINDOW FOUR METERS DISTANT *a*. Yellow spot. *b*, *b*. White streak of nerve-fibers.—(*Kühne*.)

The Horopter.—When the eyes are in the so-called secondary position—that is, in a position in which the visual axes are converged and directed to a point in front of and in the middle plane of the body—it will be found on examination that rays of light from a number of other objects enter the eye, pass through the nodal point, and fall on corresponding parts of the two retinæ and give rise to but single images. All such points lie, for the horizontal line of separation, on a line termed the *horopter*. The form of this line is that of a circle which passes through the fixation point and the two nodal points. Any object on the horopter will give rise to but a single image. This is shown in Fig. 334, in which the objects I, II, III project their rays into both eyes which fall on corresponding areas.

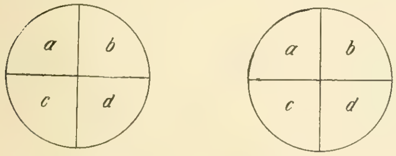

FIG. 333.—CORRESPONDING AREAS OF THE RETINA.

In addition to the horopter for the horizontal line of separation, there is also an horopter for the vertical line of separation. At a distance of two meters the vertical horopter is a plane. Within this distance it is concave to the face; beyond this distance it is convex.

An object which lies either in front of or behind the fixation point will project its rays on parts of the retinæ which do not correspond, and hence give rise to double images. This is evident from examination of Fig. 335. While the eyes are directed to figure 2, of which there is but a single image, the objects B and A give rise to double images, for reasons already given. If the eyes are now directed to B, double images will be formed of 2 and A.

At all times, therefore, double images are formed on the retinæ the existence of which is scarcely noticed unless the attention is directed to them. This is due to the fact that many of the images fall on the peripheral, less sensitive parts of the retinæ. At the same time, from a want of accommodation and the formation of diffusion-circles, they are indistinct. For these reasons they are readily neglected.

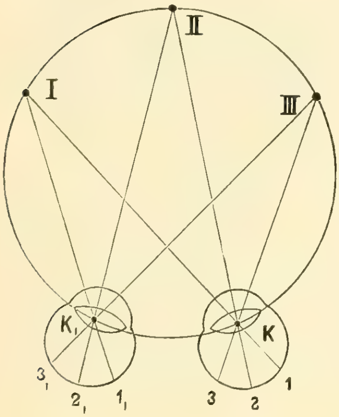

FIG. 334.—HOROPTER FOR THE SECONDARY POSITION, WITH CONVERGENCE OF THE VISUAL AXES. —(*Landois.*)

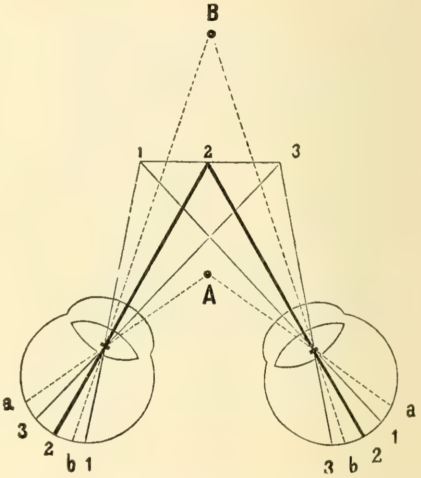

FIG. 335.—SCHEME OF IDENTICAL AND NON-IDENTICAL POINTS OF THE RETINA.—(*Landois.*)

In the primary position of the eyes—that is, a position in which the visual axes are parallel—the horopter is a plane in infinity. In the tertiary position the horopter is a curve of complex form.

Movements of the Eyeball.—The almost spheric eyeball lies in the correspondingly shaped cavity of the orbit, like a ball placed in a socket, and is capable of being moved to a considerable extent by the six muscles which are attached to it. These muscles are the superior and inferior recti, the external and internal recti, and the superior and inferior obliqui (Fig. 336). The *four recti* muscles arise from the apex of the orbit cavity, from which point they pass forward to be inserted into the sclera about 7 to 8 mm. from the corneal border. The *superior oblique* muscle having a similar origin passes forward to the upper and inner angle of the orbit cavity, at which point its tendon passes through a cartilaginous pulley, after which it is reflected backward to be inserted into the superior surface of the sclera about 16 mm. behind the corneal border. The *inferior oblique* muscle arises from the inner and inferior angle of the orbit cavity. It then passes outward, upward, and backward, to be inserted into the upper, posterior and temporal portion of the sclera about 4 or 5 mm. from the optic nerve entrance.

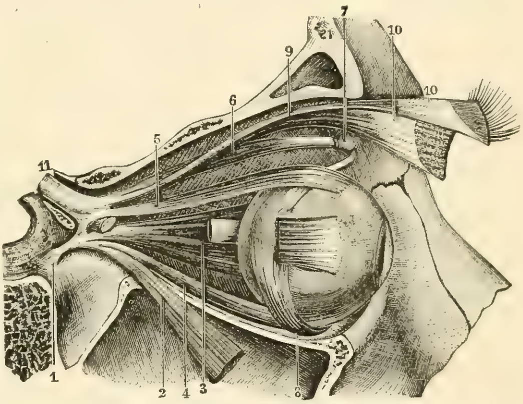

Fig. 336.—Muscles of the Eye. Tendon or Ligament of Zinn. 1. Tendon of Zinn. 2. External rectus divided. 3. Internal rectus. 4. Inferior rectus. 5. Superior rectus. 6. Superior oblique. 7. Pulley for superior oblique. 8. Inferior oblique. 9. Levator palpebræ superioris. 10, 10. Its anterior expansion. 11. Optic nerve.—(*Sappey.*)

The movements of each eye are referred to three fixed lines or axes, which have their origin at the point of rotation of the eyeball, this point lying about 1.7 mm. behind the center of the globe. If the eye looks straight forward in the horizontal plane (the head being erect), the line joining the center of rotation with the object looked at is the *line of fixation* or *line of regard.* Around this antero-posterior axis the eye may be regarded as performing its circular *rotation* or *torsion.* At right angles to this line, and joining the center of rotation of both eyes, is the *horizontal* or *transverse axis*, around which the movements of elevation (up to 34 degrees) and depression (down to 57 degrees) take place. At right angles to both of these lines there is the *vertical axis*, around which the movements of adduction (toward the nose up to 45 degrees) and abduction (toward the temple up to 42 degrees) occur. The six muscles may be divided into three pairs, each of which has a common axis around which it tends to move the eyeball. But only the common axis of the internal and external recti coincides with one of three axes before mentioned—namely, with the vertical axis—thus moving the ball only inwardly or outwardly—respectively. The other two pairs, however, have their own axes of action, and their movements of the ball must be, therefore, analyzed with regard to all the three axes, each of these four muscles producing rotation, elevation, and depression, and abduction or adduction. The superior and inferior recti muscles, forming one pair, move the eye around a horizontal axis which intersects the median plane of the body in front of the eyes at an angle of 63 degrees, and the superior and inferior oblique muscles forming the third pair rotate the globe around a horizontal axis which cuts the median plane of the body behind the eyes at an angle of 39 degrees. Thus it is that each muscle moves the eye as follows, the movement for practical purposes being referred to the cornea: The rectus externus draws the cornea simply to the temporal side, the rectus internus simply to the nose; the superior rectus displaces the cornea upward, slightly inward, and turns the upper part toward the nose (medial torsion); the inferior rectus moves the cornea downward, slightly inward, and twists the upper part away from the nose (lateral torsion); the superior oblique displaces the cornea downward, slightly outward, and produces medial torsion; while the inferior oblique moves the cornea upward, slightly outward, and produces lateral torsion. These facts show that for certain movements of the eye at least three muscles are necessary (see following table):

Inward,	Rectus internus.
Outward,	Rectus externus.
Upward,	Rectus superior. Obliquus inferior.
Downward,	Rectus inferior. Obliquus superior.
Inward and upward,	Rectus internus. Rectus superior. Obliquus inferior.
Inward and downward,	Rectus internus. Rectus inferior. Obliquus superior.
Outward and upward,	Rectus externus. Rectus superior. Obliquus inferior.
Outward and downward,	Rectus externus. Rectus inferior. Obliquus superior.

If both eyes have their line of vision in the horizontal plane parallel with each other and with the median plane of the body, they are said to be in the *primary position*. All other positions are called *secondary*. Both eyes always move simultaneously, which is called the *associated movement of the eyes*. There are three forms of associated movements: (1) movement of both eyes in the same direction; (2) movements of convergence by which the visual lines are converged on a point in the middle line of the body; (3) movements of divergence, by which the eyes are brought back from convergence to parallelism, or even to divergence, as in certain stereoscopic exercises. A combination of (1) and (2) or of (1) and (3) takes place for certain positions of the object looked at.

Color-perception.—A beam of sunlight passed through a glass prism is decomposed into a series of colors—red, orange, yellow, green, blue, and violet—the so-called *spectral colors*, so well exemplified in the rainbow. The spectral colors are termed *simple colors*, because they can not be any further decomposed by a prism. Objectively, the spectral colors consist of very rapid transverse vibrations of the ether, from about 400 millions of millions per second for red to about 760 millions of millions for violet, but subjectively they are sensations caused by the impact of the ether-waves on the percipient layer of the retina.

It is possible to mix or blend these spectral color-sensations in the eye by stimulating the same area of the retina by different spectral colors, either at the same time or in rapid succession. The following table shows the results of such experiments as performed by v. Helmholtz (Dk. = dark; Wh. = whitish):

	VIOLET.	INDIGO.	CYAN-BLUE.	BLUISH-GREEN.	GREEN.	GREENISH-YELLOW.	YELLOW.
Red.	Purple.	Dk.-rose.	Wh.-rose.	White.	Wh.-yellow.	Gold-yellow.	Orange.
Orange.	Dk.-rose.	Wh.-rose.	White.	Wh.-yellow.	Yellow.	Yellow.	......
Yellow.	Wh.-rose.	White.	Wh.-green.	Wh.-yellow.	Gr.-yellow.	......	......
Gr.-yellow.	White.	Wh.-green.	Wh.-green.	Green.	......	......	......
Green.	White-blue.	Water-blue.	Bl.-green.	......	......	.... .	......
Bluish-green.	Water-blue.	Water-blue.	......	......	......	......	......
Cyan-Blue.	Indigo.	...	......	......	......	......	......

These are the *mixed colors*. But it is to be observed that only two new color-sensations can be produced, white and purple, the remaining mixed colors already finding their equivalent in the spectrum. White and purple, therefore, are color-sensations which have no objective equivalent in a simple number of ether-vibrations like the spectral colors.

Two spectral colors which by their mixture produce the sensation of white are called *complementary colors*. Such are red and green-blue, golden yellow and blue, green and violet. The mixture of all the spectral colors produces white again. This is the result of adding two or more *color-sensations*. Different results are obtained, however, by adding color *pigments*. Yellow and blue, for example, produce in the eye white, but on the painter's palette green. The colors of nature are usually mixtures of simple colors, as can be shown by spectroscopic analysis or by a synthesis of spectral colors.

In all color-sensations we must distinguish three primary qualities: (1) hue; (2) purity or tint; (3) brightness or luminosity. The first quality gives the main name to the color—*e. g.*, red or blue—this depending on the spectral color or the mixture of two spectral colors with which it can be matched. The second quality, the tint, depends on the admixture of white with the ground color; and the third quality, brightness, depends on the objective intensity of the light and the subjective sensitiveness of the retina. Color-perception thus far refers only to the most sensitive part of the retina. At the more peripheral parts of the retina the colors are seen somewhat differently, as is shown by the following table giving the limits up to which the colors are recognized:

	White.	Blue.	Red.	Green.
Externally	90°	80°	65°	50°
Internally	60°	55°	50°	40°
Superiorly	45°	40°	35°	30°
Inferiorly	70°	60°	45°	35°

Theories of Color-perception.—The *theory of v. Helmholtz*, originated by Thomas Young (1807), assumes in its latest form the existence in the human retina of three different kinds of end-organs, each of which is loaded with its own photo-chemical substance capable of being decomposed by a certain color, and thus exciting the fiber of the optic nerve.

In the first group these end-organs are loaded with a red-sensitive substance, which is affected mainly by the red part of the spectrum; the second group has its end-organs provided with a green-sensitive substance, which is mainly excited by the green color; while the third group is provided with a blue-sensitive substance, this latter being mainly affected and decomposed by the blue-violet portion of the spectrum. All these three different end-organs are present in every part of the most sensitive area of the retina, and are connected by separate nerve-fibers with special parts of the brain, in the cells of which each calls up its separate sensation of red or green or blue.

Out of these three primary color-sensations all other color-sensations arise. If a light mainly excites the red- or green- or blue-sensitive substance of a retinal area, we term it red, green, or blue, respectively. But if two of these photo-chemical substances are stimulated simultaneously, quite different sensations arise. Thus simultaneous stimulation of the red and green substances gives rise to the sensation of yellow, that of red and blue to the sensation of purple, and that of blue and green to the sensation of blue-green. Simultaneous stimulation of all three substances of a certain area produces the sensation of white. According to this theory, complementary colors are all those which together excite all the three substances. *Color-blindness* is explained by this theory, on the assumption that two of the photo-chemical substances have become similar or equal in composition to each other.

The *theory of Hering*, brought forward in 1874, has the underlying assumption that the process of restitution in a nerve-element is capable of exciting a sensation. This theory asserts that there are three visual substances in the retina—a white-black, a red-green, and a yellow-blue visual substance. A destructive process in the white-black substance, such as is induced not only by white light, but also by any other simple or mixed color, produces the sensation of white, while the process of restitution or assimilation in this substance produces the sensation of black. Similarly, red light produces disassimilation or decomposition in the red-green substance, and this, again, the sensation of red. Green light, however, favors the process of restitution or assimilation in the red-green substances, and thus gives rise to the sensation of green. In the same way the sensation of yellow has its cause in the decomposition of yellow-blue substance induced by yellow light, while the sensation of blue is produced by an assimilative process in the same substance. Simultaneous processes of disassimilation and assimilation in the same visual substance antagonize each other, and consequently produce no color-sensation by means of this substance, but only the sensation of white, by reason of decomposition, by both colors, in the white-black substance. Thus, yellow and blue, impinging on the same retinal area, have no effect on the yellow-blue substance, because they are antagonistic in their action on this substance, but only produce the sensation of white, as both yellow and blue decompose the white-black material. *Color-blindness* is explained by the assumption of the absence of either the red-green or the yellow-blue visual substance in the retina.

Accessory Structures.—The eyeball is protected anteriorly by the eyelids and their associated structures, the Meibomian glands, the lachrymal glands, and tears.

The *eyelids* consist of a central framework of connective tissue supporting muscle tissue (the orbicularis palpebrarum muscle) and glands, and covered externally by skin and internally by a modified skin, the conjunctiva. The free border of each lid is strengthened by a semilunar plate of dense fibrous tissue, the tarsus. The cutaneous edge of the lid is bordered with short stiff hairs. At the inner extremity each eyelid presents a small opening, the *punctum lacrimale*, the beginning of the lachrymal duct. The two ducts after uniting open into the nasal duct.

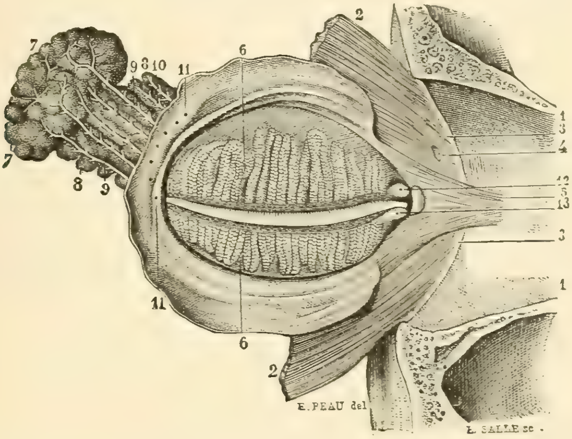

FIG. 337.—THE LACRIMAL AND MEIBOMIAN GLANDS, AND ADJACENT ORGANS OF THE EYE. 1, 1. Inner wall of orbit. 2, 2. Inner portion of orbicularis palpebrarum. 3, 3. Attachment to circumference of base of orbit. 4. Orifice for transmission of nasal artery. 5. Muscle of Horner (tensor tarsi). 6, 6. Meibomian glands. 7, 7. Orbital portion of lacrimal gland. 8, 9, 10. Palpebral portion. 11, 11. Mouths of excretory ducts. 12, 13. Lacrimal puncta.—(*Sappey.*)

The *Meibomian glands* are modified sebaceous glands imbedded in the posterior portion of the lids (Fig. 337). Their ducts open on the free border of the lid. These glands secrete an oleaginous material resembling sebaceous matter which accumulates along the margin of the lid and prevents the tears from flowing down the cheek.

The *lachrymal gland* is situated at the upper and outer part of the orbit cavity. It consists of a series of compound tubules lined by epithelium. The secretion (the tears) is conducted from the gland to the outer part of the conjunctiva by seven or eight ducts. The lachrymal secretion consists of water and inorganic salts. It is distributed over the corneal surface during the act of winking, thus keeping it moist and free from foreign particles. It eventually passes into the lachrymal ducts and then into the nose. The lachrymal glands receive secretory fibers by way of the fifth nerve and the cervical sympathetic. The secretion can be excited reflexly from stimulation of sensor nerves as well as by emotional states.

CHAPTER XXVIII.

THE SENSE OF HEARING.

The physiologic mechanism involved in the sense of hearing includes the ear, the auditory nerve, its cortical connections, and nerve-cells in the cortex of the temporal lobe.

Peripheral excitation of this mechanism develops nerve impulses which, transmitted to the cortex, evoke the sensation of sound and its varying qualities—intensity, pitch, and timbre.

The specific physiologic stimulus to the terminal organ, the organ of Corti, is the impact of atmospheric undulations of varying energy and rapidity.

THE PHYSIOLOGIC ANATOMY OF THE EAR.

The ear, the organ of hearing, is lodged within the petrous portion of the temporal bone. It may, for convenience of description, be divided into three portions: viz., the external, the middle, and the internal portions (Fig. 338).

The **external ear** consists of the *pinna* or *auricle* and the *external auditory canal.* The *pinna* is composed of a thin layer of cartilage which presents a series of elevations and depressions. It is attached by fibrous tissue to the outer edge of the auditory canal and covered by a layer of skin continuous with that covering adjacent structures. The general shape of the pinna is concave. Its anterior surface presents, a little below the center, a deep depression—the *concha.*

The *external auditory canal* extends from the concha inward for a distance of from 25 to 30 mm. It is directed at first upward, forward, inward, and then downward to its termination. It is composed partly of bone and partly of cartilage and lined by a reflection of the skin covering the pinna. At the external portion of the canal the skin contains a number of tubular glands, the *ceruminous glands,* which resemble in their conformation the perspiratory glands. They secrete cerumen or ear-wax.

The **middle ear,** or **tympanum,** is an irregularly shaped cavity hollowed out of the temporal bone and situated between the external auditory canal and the internal ear. It is narrow from side to side, though wider above than below. It is relatively long in its antero-posterior and vertical diameters. The upper portion is known as the attic. The middle ear is in communication posteriorly with the mastoid cells, anteriorly with the pharynx through the Eustachian tube.

The Eustachian Tube.—The passageway between the tympanic cavity and the naso-pharynx is known from its discoverer as the Eustachian tube. It is composed internally of bone, externally of cartilage, and is lined by mucous membrane covered with ciliated epithelium. Near the middle of its course the tube is contracted, though expanded at either extremity (Fig. 338). It measures about 40 mm. in length. Its general direction from the pharyngeal orifice is outward, backward, and upward at an angle of about 45 degrees.

The middle ear cavity is separated from the external ear by a membrane—the membrana tympani—and from the internal ear by an osseo-membranous partition which forms a common wall for both cavities. The interior of the cavity is crossed from side to side by a chain of bones and lined by a mucous membrane continuous with that lining the pharynx.

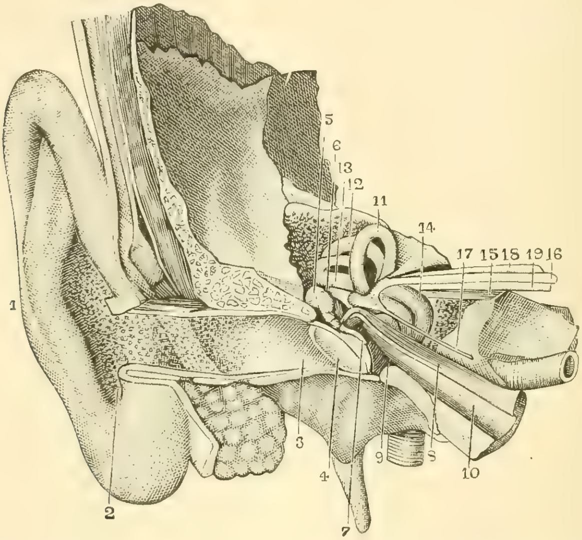

FIG. 338.—THE EAR. 1. Pinna, or auricle. 2. Concha. 3. External auditory canal. 4. Membrana tympani. 5. Incus. 6. Malleus. 7. Manubrium mallei. 8. Tensor tympani. 9. Tympanic cavity. 10. Eustachian tube. 11. Superior semicircular canal. 12. Posterior semicircular canal. 13. External semicircular canal. 14. Cochlea. 15. Internal auditory canal. 16. Facial nerve. 17. Large petrosal nerve. 18. Vestibular branch of auditory nerve. 19. Cochlear branch.—(*Sappey.*)

The *membrana tympani* is a thin, translucent, nearly circular membrane, measuring about 10 mm. in diameter, placed at the inner termination of the external auditory canal. It is inclosed in a ring of bone which in the fetal condition can be easily removed, but in the adult condition can not be removed, owing to its consolidation with the surrounding bone. This membrane consists primarily of a layer of fibrous tissue which is covered externally by a thin layer of skin continuous with that lining the auditory canal, and internally by a thin mucous membrane. The tympanic membrane is placed obliquely at the bottom of the auditory canal, inclining from above and behind downward and forward at an angle of about forty-five degrees. The external surface of this membrane presents a funnel-shaped depression, the sides of which are slightly convex.

The Ear-bones.—Running across the tympanic cavity and forming an irregular line of joined levers is a chain of bones, which articulate one with another at their extremities. These bones are known as the *malleus, incus,* and *stapes.* The form and arrangement of these bones are shown in Figs. 339, 340.

The *malleus*, or hammer bone, consists of a head, neck, and handle, of which the latter is attached to the inner surface of the membrana tympani. The *incus* or anvil bone presents a concave articular surface which receives the head of the malleus. The stapes, or stirrup-bone, articulates externally with the long process of the incus, and internally, by its oval base, with the edges of an oval opening, the foramen ovale. The entire chain is partially supported by a ligament attached to the short process of the incus and to the walls of the tympanic cavity.

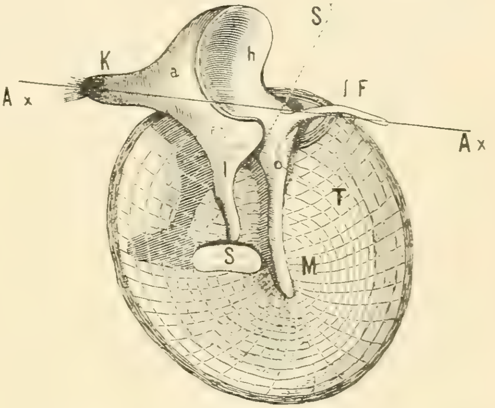

FIG. 339.—TYMPANIC MEMBRANE AND THE AUDITORY OSSICLES (LEFT) SEEN FROM WITHIN, *i. e.*, FROM THE TYMPANIC CAVITY. *M.* Manubrium or handle of the malleus. *T.* Insertion of the tensor tympani. *h.* Head. *lF.* Long process of the malleus. *a.* Incus, with the short (*K*) and the long (*l*) process. *S.* Plate of the stapes. *Ax*, *Ax*, is the common axis of rotation of the auditory ossicles. S^1. The pinion-wheel arrangement between the malleus and incus.—(*Landois.*)

The Tensor Tympani Muscle.—This is a delicate muscle, about 15 mm. in length, situated in a narrow groove just above the Eustachian tube (Fig. 341). It arises from the cartilaginous portion of the Eustachian tube and the adjacent portion of the sphenoid bone. From this origin it passes nearly horizontally backward to the tympanic cavity; just opposite to the foramen ovale, its tendon bends at a right angle over the processus cochleariformis and then passes outward across the tympanic cavity to be inserted into the handle of the malleus near the neck.

The *stapedius muscle* emerges from the cavity of a pyramid of bone which projects from the posterior wall of the tympanum. Its tendon passes forward to be inserted into the neck of the stapes bone near its point of articulation with the incus.

The **internal ear, or labyrinth,** is located within the petrous portion of the temporal bone. It consists of an osseous and a membranous portion, the latter contained within the former.

The **osseous labyrinth** is subdivided into vestibule, semicircular canals, and cochlea.

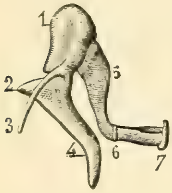

FIG. 340.—AUDITORY OSSICLES. 1. Head of malleus. 2. Processus brevis. 3. Processus gracilis. 4. Manubrium. 5. Long process of incus. 6. Articulation between incus and stapes. 7. Stapes. —(*Sappey.*)

The *vestibule* is a small, triangular-shaped cavity between the semicircular canals and the cochlea. It is separated from the cavity of the middle ear by an osseous partition which presents near its center an oval opening, the *foramen ovale.* In the living condition this opening is closed by the base of the stapes bone, which is held in position by an annular ligament. The inner wall presents a number of openings for the passage of nerve-fibers (Fig. 342).

The *semicircular canals* are three in number, a superior vertical, an inferior vertical, and a horizontal, each of which opens by two orifices into the cavity of the vestibule, with the exception of the two vertical, which unite at one extremity and then open by a single orifice. Each canal near its vestibular orifice is enlarged to almost twice the size of the rest of the canal, forming what is known as the ampulla.

The *cochlea,* the anterior portion of the labyrinth, is a gradually tapering canal, about 35 mm. in length, wound spirally two and a half times around a central bony axis, the *modiolus.* The cavity of the cochlea is partially subdivided into two cavities by a thin spiral plate of bone which projects from the inner wall, known as the *lamina osseous spiralis.* In the natural condition this partition is completed by a connective-tissue membrane, so that the two passages are completely separated from each other. The *upper* passage or scala is in free communication with the vestibule, and is known as the *scala vestibuli;* the *lower* passage or scala in the dead condition communicates with the tympanum by means of a round opening, the *foramen rotundum,* and is therefore known as the *scala tympani.* In the living condition this opening is completely closed by a membrane, a second membrana tympani. Both the scalæ vestibuli and tympani communicate at the apex of the cochlea by a small opening, the helicotrema. The modiolus, the central bony axis, is perforated from base to apex by a canal for the passage of the auditory nerve-fibers; lateral canals, diverging from the central canal, pass through the osseous lamina spiralis and transmit fibers of the auditory nerve. The interior of the bony labyrinth is

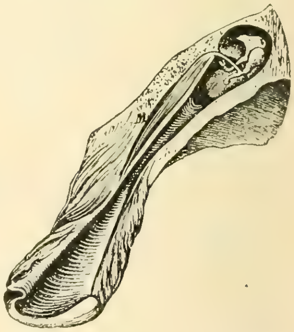

FIG. 341.—M, THE TENSOR TYMPANI MUSCLE—THE EUSTACHIAN TUBE (LEFT).—(*Landois.*)

lined by periosteum covered by epithelium and in communication with lymph-spaces at the base of the skull by means of the aqueduct of the vestibule.

The **membranous labyrinth,** lying within the osseous labyrinth, corresponds with it in form, though it is smaller in size. It may be subdivided into vestibule, semicircular canals, and cochlea (Fig. 343).

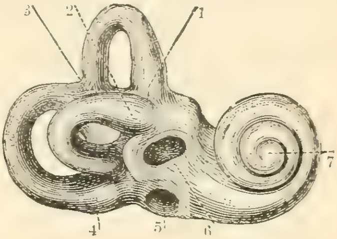

FIG. 342.—BONY COCHLEA. 1. Ampulla of superior semicircular canal. 2. Horizontal canal. 3. Junction of superior and posterior semicircular canals. 4. The posterior semicircular canal. 5. Foramen rotundum. 6. Foramen ovale. 7. Cochlea.

The *vestibular portion* consists of two small sacs, the *utricle* and the *saccule,* which communicate with each other by means of the two branches of a duct passing through the aqueduct of the vestibule—the *ductus endolymphaticus.*

The *semicircular canals* communicate with the utricle in the same manner as the bony canals communicate with the vestibule. The saccule communicates with the membranous cochlea by a short canal, the *canalis reuniens.* The walls of the utricle, saccule, and semicircular canals are composed of connective tissue lined by epithelium. At the points of entrance of the auditory nerve, the *maculæ acusticæ,* in all three structures, the epithelium undergoes a marked change in appearance and structure. It becomes columnar in shape and provided with stiff hair-like processes or threads, which project into the cavity. In the saccule and utricle the hair-like processes are covered by a layer of small crystals of calcium carbonate held together by a gelatinous material. The crystals are known as otoliths (Fig. 344).

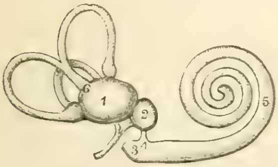

FIG. 343.—1. Utricle. 2. Saccule. 3. Vestibular end of cochlea. 4. Canalis reuniens. 5. Membranous cochlea. 6. Membranous semicircular canal.—(*Potter's "Anatomy."*)

The fibers of the *vestibular nerve,* arising from the cells of the ganglion of Scarpa in the internal auditory meatus, send their peripherally directed branches through the foramina in the inner wall of the vestibule, through the walls of the utricle and semicircular canals near the ampulla. As the fibers approach the maculæ acusticæ they subdivide into delicate fibrillæ, which ultimately become histologically and physiologically related to the neuro-epithelium. From the relation of the nerve-fibers to the epithelium, the latter must be regarded as the highly specialized *terminal organ* of the *vestibular portion* of the auditory nerve.

The *cochlea* is a closed membranous tube situated between the osseous lamina spiralis and the outer bony wall. A transection of the entire cochlea shows the relation of the osseous and membranous portions (Fig. 345). The cochlear tube is triangular in shape. The base is attached to the bony wall, the apex to the edge of osseous lamina spiralis. One side of the tube forms in part the membrane of Reissner, the other side forms in part the basilar membrane. The sides of the cochlea toward the scala vestibuli and scala tympani are covered with epithelium. The triangular cavity of the cochlear tube is known as the *scala media*. The *inner surface* of the cochlear tube is lined by epithelium, which becomes extraordinarily modified and specialized along the surface of the basilar membrane, to constitute what is known as—

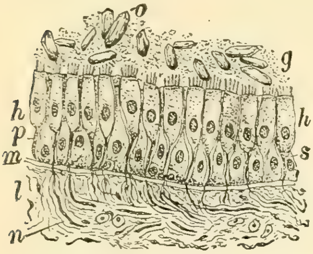

Fig. 344.—Section of Wall of Utricle of the Internal Ear, through macular region, from rabbit, showing otoliths (*o*), embedded within granular substance (*g*). *h*. Ciliated cells with processes. (*p*), extending between sustentacular elements (*s*). *m*. Basement membrane. *n*. Nerve-fibers within fibrous tissue (*l*) passing toward hair-cells and becoming non-medullated at basement-membrane.—(*After Piersol.*)

The Organ of Corti.—In Fig. 345 this organ is represented as it appears on cross-section of the cochlea. It consists primarily of an arch composed of two modified epithelial cells known as the rods or pillars of Corti, which rest below on the basilar membrane, but meet and interlock above; it consists secondarily of a series of columnar epithelial cells provided with hair-like processes which rest upon and are supported by the rods both on the inner and outer aspects of the arch. The space beneath the arch is known as the tunnel. The inner hair cells are not nearly so numerous as the outer hair cells The epithelial cells external to the outer and inner hair cells are supporting or sustentacular in character.

The organ of Corti extends the entire length of the cochlea. The number of rods which, standing side by side, form the inner limb of the arch is estimated at 5600; the number which form the outer limb is estimated at 3850. The outer rods are broader than the inner and at some places articulate with two or three inner rods. The upper edges of the rods are flattened, elongated, and project outward, forming a reticulated membrane through the meshes of which the hair-like processes of the cells project.

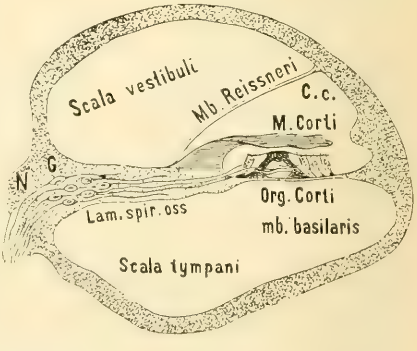

Fig. 345.—A Transverse Section of a Turn of the Cochlea.

From the connective-tissue thickening on the upper surface of the osseous lamina spiralis there extends outward over the organ of Corti a thin membrane, the *membrana tectoria*. The common cavity between the walls of the osseous and membranous labyrinth in the vestibule, the semicircular canals, in the scala vestibuli and scala tympani of the cochlea, is filled with a clear fluid—the *perilymph;* the common cavity within the walls of the entire membranous labyrinth is also filled with a similar fluid—the *endolymph.* The hair-like processes of the epithelial cells covering the maculæ acusticæ and the rods of Corti are consequently bathed by endolymph. Both fluids are in relation with the subarachnoid lymph-spaces at the base of the brain, the perilymph through the aqueduct of the vestibule, the endolymph through the endolymphatic duct.

The fibers of the cochlear nerve, arising from the ganglion cells of the *spiral ganglion* situated in the osseous lamina spiralis near the modiolus, send their peripheral branches to the saccule and to the organ of Corti. As they approach this structure they lose their medullary sheath and become naked axis-cylinders. The fibers then divide into two parts, of which one passes to the inner hair cells; the other passes between the inner rods and crosses the tunnel between the outer rods to the outer hair cells. The exact method of termination of these fibers in the hair cells is unknown, but doubtless it is both histologic and physiologic.

From the relation of the nerve-fibers to the organ of Corti the latter must be regarded as the highly specialized *terminal organ* of the cochlear division of the auditory nerve.

THE PHYSIOLOGY OF AUDITION.

The general function of the ear is the reception and transmission of atmospheric vibrations from the concha to the percipient elements —the hair cells—of the organ of Corti. The vibratory excitation of these end-organs thus caused, is the basis of auditory perceptions. The atmospheric vibrations are collected by the pinna and concha, conveyed by the auditory canal to the tympanic membrane, transmitted by the chain of bones to the labyrinth to pass successively through the perilymph, the membranous walls, the endolymph, to the hair cells. The nerve impulses generated by these vibrations are then transmitted by the cochlear nerve to the auditory centers of the cerebrum, where the sensations of sound are evoked. In order to appreciate the function of the individual structures concerned in this general function there must be kept in mind a few of the characteristics of atmospheric vibrations.

Atmospheric Vibrations.—The vibrations of the atmosphere which are the objective causes of the sensations of sound are communicated to it by the vibrations of elastic bodies such as tuning-forks, rods, strings, membranes, etc. These produce in the air a to-and-fro movement of its particles, resulting in a succession of alternate condensations and rarefactions which are propagated in all directions. The impact of a rhythmic succession of such condensations on the ear gives rise to musical sounds; the impact of an arrhythmic or irregular succession gives rise to noises.

If a writing point attached to a tuning-fork in vibration be placed in contact with a traveling recording surface, each vibration will be recorded in the form of a wave. For this reason atmospheric vibrations are generally spoken of as sound-waves. A line drawn horizontally through such a curve indicates the position of rest of the fork; the extent of the curve on each side of this line indicates the excursion of the fork or the amplitude of its movement.

The sounds which physiologically result from the impact and transmission of the effects of sound-waves, possess intensity, pitch, and quality or tone.

The *intensity* or loudness of a sound depends on the amplitude of the vibration which causes it. The greater the amplitude or swing of the vibrating body, the greater is the energy with which it strikes the ear.

The *pitch* of a sound depends on the number of vibrations which strike the ear in a unit of time—a second. The greater the number, the higher the pitch. Thus while the pitch of the sound caused by the note C, on the first leger line below, of the music scale, corresponds to 256 vibrations, the pitch of the sound caused by the note C an octave above, corresponds to 512 vibrations. The lowest rate of vibration which can produce a distinct sound varies in different individuals from 14 to 18; the highest rate varies from 35,000 to 40,000 per second. Between these two extremes lies the range of audibility, which embraces about 11 octaves. Vibrations less than 14 per second can not be perceived as a continuous sound; vibrations beyond 40,000 also fail to be so perceived. In the ascent of the music scale from the lowest to the highest regions there is a gradual increase in the vibration frequency.

The *quality* of a sound depends on the *form* of the vibration. It is this feature which gives rise to those differences in sensations which permit one to distinguish one instrument from another when both are emitting the same note. The form of the sound-wave in any given instance is the resultant of a combination of a fundamental vibration and certain secondary vibrations of subdivisions of the vibrating body. These secondary vibrations give rise to what is known as overtones. By their union with and modification of the fundamental vibration there is produced a special form of vibration which gives rise not to a simple but a composite sensation. It is for this reason that the same note of the piano, the violin, and the human voice varies in quality.

The Function of the Pinna and External Auditory Canal.—In those animals possessing movable ears the *pinna* plays an important part in the collection of sound-waves. In man it is doubtful if it plays a part at all necessary for hearing. Nevertheless an individual with defective hearing may have the perception of sound increased by placing the pinna at an angle of 90 degrees to the side of the head or by placing the hand behind it. The *external auditory* *canal* transmits the sonorous vibrations to the tympanic membrane From the obliquity of this canal it has been supposed that the vibrations, after passing the concha, undergo a series of reflections on their way to the tympanic membrane, which, owing to its inclination, would be struck by them in a much more effective manner.

The Function of the Tympanic Membrane.—The function of the tympanic membrane is the reception of the atmospheric vibrations which are transmitted to it. This it does by vibrating in unison with them. The vibrations which the membrane exhibits correspond in amplitude, in frequency, and in form to those of the atmosphere. That this membrane actually reproduces all vibrations within the range of audibility has been experimentally demonstrated. The membrane not being fixed, as far as its tension is concerned, does not possess a fixed fundamental note, like a stationary fixed membrane, and is therefore just as well adapted for the reception of one set of vibrations as another. This is made possible by variations in its tension in accordance with the pitch of frequency of the atmospheric vibrations. In the absence of vibration the membrane is in a condition of relaxation; with the advent of sound-waves possessing a gradual increase of pitch, as in the ascent of the music scale, the tension of the membrane increases until its maximum is reached at the upper limit of the range of audibility. By this change in tension certain tones become perceptible and distinct, while others become imperceptible and indistinct.

The Function of the Tensor Tympani Muscle.—The function of this muscle is, as its name indicates, to change and to fix the tension of the tympanic membrane, so that it can most readily vibrate in unison with vibrations of varying degrees of rapidity. The tendon of this muscle playing around the processus cochleariformis is attached almost at a right angle to the handle of the malleus. Hence as the muscle contracts it exerts its traction from the process and draws the handle of the malleus inward, thus increasing the convexity of the tympanic membrane and at the same time its tension. With the relaxation of the muscle the handle of the malleus passes outward, and the convexity and tension diminish.

In the ascent of the music scale, each note corresponding to an increase in vibration frequency, requires for its perception an increase in tension and an increase in the force of the contraction of the tensor muscle. In the descent of the music scale the reverse conditions obtain. The contraction of the muscle is of the nature of a single twitch, and of just sufficient force and duration to tense the membrane for a given rate of vibration.

The contraction of the muscle is excited reflexly. The afferent path is through fibers of the trigeminal nerve distributed to the tympanic membrane; the efferent path is through fibers in the small root of the trigeminal. The stimulus is sudden pressure on the tympanic membrane. The more frequently and forcibly the stimulus is applied, the greater is the muscle response. The tensor tympani muscle may therefore be regarded as an accommodative apparatus by which the tympanic membrane is adjusted for the reception of vibrations of varying degress of frequency.

The Function of the Chain of Bones.—The function of the chain of bones is to transmit the effects of the atmospheric vibrations to the fluid of the labyrinth. The manner in which this is accomplished becomes evident from the relation which the bones of this chain bear to one another and to the tympanic membrane on the one hand and to the fluid of the labyrinth on the other.

When pressure is made on the outer surface of the tympanic membrane it is at once pushed inward, carrying with it the handle of the malleus, the head at the same time rotating outward around an axis corresponding to its ligamentous attachments. As the handle moves inward a small ledge of bone just below the malleo-incudal joint locks with, and hence pushes inward, the long process of the incus. Since this process is united at almost a right angle to the stapes bone, the latter is forced toward and into the foramen ovale, thus producing a pressure on the perilymph. With the cessation of the pressure the elastic forces of the membrane and of the ligaments return the handle of the malleus to its former position; by the unlocking of the malleo-incudal joint the entire chain also returns to its former position without exerting undue traction on the basal attachment of the stapes.

As the long process of the incus is shorter than the handle of the malleus, and as the movement between them takes place around an axis from before backward, it follows that the excursion of the incus and stapes will be less than that of the malleus, while the force will be greater. Hence as the vibrations are transferred from the tympanic membrane of large area to the base of the stapes of small area (20 to 1.5), they lose in amplitude but increase in force. Their pressure on the perilymph is therefore thirty times greater than on the membrana tympani. In addition to its function as a transmitter of vibrations, the chain of bones serves as a point of attachment for muscles which regulate the tension of the tympanic membrane and the pressure on the labyrinth.

The Function of the Stapedius Muscle.—The function of the stapedius muscle is a subject of much discussion. According to Henle, its function is to so adjust the stapes bone that it will be prevented from exerting an undue pressure on the perilymph during the inward excursions of the incus process. According to Toynbee, its function is to press the posterior part of the stapes inward, make it a fixed point, and place the anterior part in such a position that it will vibrate freely and accurately.

The Function of the Eustachian Tube.—In order that the tympanic membrane may vibrate freely it is essential that the air pressure on both sides shall be equal at all times. This is made possible by the Eustachian tube. Were it not for this passageway, with each inward swing of the membrane the air in the tympanic cavity would be condensed and its pressure raised, in consequence of which the movement of the membrane would be retarded; with each outward swing, the air would be rarefied and its pressure lowered below that of the atmosphere, and in consequence the movement outward would be retarded; the maximum response, therefore, of the membrane to a given vibration could not be attained and the resulting sound would be muffled and indistinct. But as with each vibration of the membrane the air can pass into and out of the tympanum through this tube, inequalities of pressure are prevented and a free vibration permitted.

The impairment in the acuteness of hearing which is caused by either a rise or fall of pressure in the middle ear can be shown—

1. By closing the mouth and nose and then forcing air from the lungs through the Eustachian tube into the tympanum, thus increasing the pressure.
2. By closing the mouth and nose and then making an effort of deglutition. As this act is attended by an opening of the pharyngeal end of the Eustachian tube, the air in the tympanum is partly withdrawn and the pressure lowered. In each instance hearing is impaired. After either experiment the normal condition is restored by swallowing with the nasal passages open.

The Functions of the Internal Ear.—From the anatomic arrangement of the structures of the internal ear it is evident that if the vibrations of the stapes bone are to reach the peripheral organs—the hair cells—of both the vestibular and cochlear nerves, they must traverse successively the perilymph, the membranous walls, and the endolymph. As the perilymph is incompressible, the inward movement of the stapes would be prevented were it not for the elastic character of the membrane closing the foramen rotundum. The pressure wave occasioned by each inward movement of the stapes is transmitted through the scala vestibuli, the helicotrema, the scala tympani, to this membrane, which by virtue of its elasticity is pressed into the tympanic cavity. With the outward movement of the stapes, equilibrium is at once restored.

The Functions of the Cochlea.—The cochlea is the portion of the internal ear which is concerned in the perception of tones. The arrangement of the histologic elements of the organ of Corti indicates that they in some way respond to the vibrations of varying frequency and form, and through the development of nerve impulses, evoke the sensations of pitch and quality. The manner in which this is accomplished is largely a matter of speculation. While many theories have been offered in explanation of the power to distinguish the pitch and the quality or timbre of a tone, most physiologists prefer that of Helmholtz, who regarded the transverse fibers of the basilar membrane as the elements immediately concerned, and compared them, both in their arrangement and power of sympathetic vibration, with the strings of a piano. He said: "If we could so connect every string of a piano with a nerve-fiber that the nerve-fiber would be excited as often as the string vibrated, then, as is actually the case in the ear, every musical note which affected the instrument would excite a series of sensations exactly corresponding to the pendulum-like vibrations into which the original movements of the air can be resolved; and thus the existence of each individual overtone would be exactly perceived, as is actually the case with the ear. The perception of tones of different pitch would, under these circumstances, depend upon different nerve-fibers, and hence would occur quite independently of each other. Microscopic investigation shows that there are somewhat similar structures in the ear. The free ends of all the nerve-fibers are connected with small elastic particles which we must assume are set into sympathetic vibration by sound-waves." (Stirling.)

The mechanism might be regarded, therefore, somewhat as follows: The sound-waves received by the membrana tympani and transmitted by the chain of bones to the fenestra ovalis produce variable pressures in the fluids of the internal ear; these pressures vary in intensity, in number, and in quality, and correspond with the intensity, pitch, and quality of the tones. If, therefore, a compound wave of pressure be communicated by the base of the stapes, it will be resolved into its constituents by the different transverse fibers of the basilar membrane, each picking out its peculiar portion of the wave and thus stimulating corresponding nerve filaments. Thus different nerve impulses are transmitted to the brain, where they are fused in such a manner as to give rise to a sensation of a particular quality, but still so imperfectly fused that each constituent, by a strong effort of attention, may be still recognized. The transverse fibers of the basilar membrane vary in length from 0.04155 mm. at the base of the cochlea to 0.495 mm. at the apex, and, according to Retzius, are about 24,000 in number. As the human ear usually cannot distinguish more than 11,064 tones, it is evident that there is a sufficient anatomic basis for this theory.

The **functions of the semicircular canals** have already been stated in connection with the chapter relating to the functions of the cerebellum.

CHAPTER XXIX.

REPRODUCTION.

Reproduction is the process by which a new individual is initiated and developed and the species to which it belongs is preserved. Reproduction is the result of the union and subsequent development of germ- and sperm-cells. These cells are produced and their union accomplished by the coöperation of the reproductive organs characteristic of the two sexes.

Embryology is a department of anatomic science which has for its object the investigation of the successive stages that the new being passes through during its gradual development prior to birth.

THE REPRODUCTIVE ORGANS OF THE FEMALE.

The reproductive organs of the female comprise the ovaries, Fallopian tubes, uterus, and vagina (Fig. 346).

The Ovaries.—The ovaries are two small, flattened bodies, measuring about 40 mm. in length and 20 in breadth. They are situated in the cavity of the pelvis, one on either side, and embedded in a fold of the peritoneum, known as the broad ligament. A section of the ovary shows that it consists externally of a thin, firm, connective-tissue membrane and internally of a fine connective-tissue stroma, supporting blood-vessels, non-striated muscle-fibers and nerves, and containing in its meshes a very large number of spheric sacs named after their discoverer, de Graaf, the *Graafian sacs* or *follicles*. These follicles are very numerous and are present in all portions of the ovary, though they are most abundant toward its peripheral portions. It is estimated that the human ovary contains from 20,000 to 40,000 follicles. The follicles vary considerably in size; while many are visible to the unaided eye, others require for their detection high powers of the microscope. Although the follicles are present in the ovary at the time of birth, it is not until the period of puberty that they assume functional activity.

From this time on to the catamenial period there is a constant growth and development of these follicles. Each follicle consists of an external investment of fibrous tissue and blood-vessels, and an internal investment of cells, the *membrana granulosa*. At the lower portion of this membrane there is an accumulation of cells, the *proligerous disc* (Fig. 347). The cavity of the follicle contains a slightly yellowish, alkaline, albuminous fluid, a transudate in all probability from the blood-vessels. The Graafian follicle is of especial interest.

for it is in this structure, and more especially in the proligerous disc, that the true germ-cell or ovum is developed.

The **ovum** is a spheric body measuring about 0.3 mm. in diameter. It consists of a mass of living, protoplasmic material, *cytoplasm*, a *nucleus* or *germinal vesicle*, and a *nucleolus* or *germinal spot*. The cytoplasm presents toward its central portion a quantity of granular material, partly fatty in character, the *deutoplasm* or *vitellus*. The peripheral portion of the cytoplasm is surrounded by a delicate radially striated border, the *zona pellucida* or *radiata* (Fig. 348).

The *nucleus* consists of a nuclear membrane enclosing contents. The latter consist of an amorphous material in which is embedded a network, some of the threads of which have a strong affinity for certain staining materials, and hence are known as *chromatin*, while others stain less deeply and are known as *achromatin*.

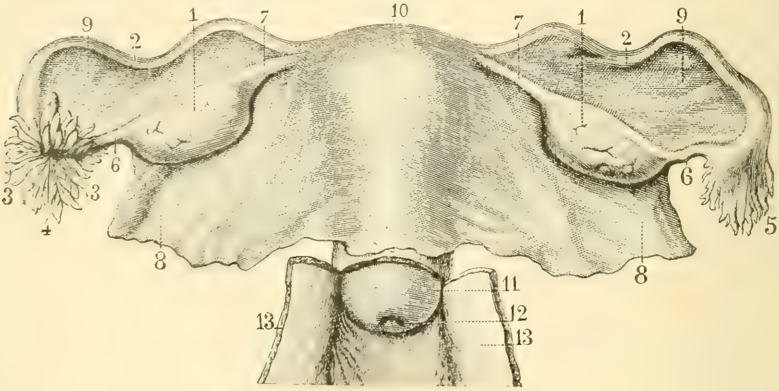

FIG. 346.—UTERUS, FALLOPIAN TUBES AND OVARIES; POSTERIOR VIEW. 1, 1. Ovaries. 2, 2. Fallopian tubes. 3, 3. Fimbriated extremity of the left Fallopian tube seen from its concavity. 4. Opening of the left tube. 5. Fimbriated extremity of the right tube, posterior view. 6, 6. Fimbriæ which attach the extremity of each tube to the ovary. 7, 7. Ligaments of the ovary. 8, 8, 9, 9. Broad ligament. 10. Uterus. 11. Cervix uteri. 12. Os externum. 13, 13. Vagina.

The Fallopian Tubes.—The Fallopian tubes are about 12 centimeters in length and extend from the upper angles of the uterus to the ovaries. Each tube is somewhat trumpet-shaped, the narrow portion being close to the uterus, the wide portion close to the ovary. The outer extremity of the tube is expanded and subdivided, and presents a series of processes termed fimbriæ, one of which is attached to the ovary. The tube consists of three coats—an external or serous; a middle or muscular, the fibers of which are arranged longitudinally and transversely; and an internal or mucous. The surface of the mucous coat is covered with a layer of ciliated epithelial cells, the motion of which is toward the uterus.

The Uterus.—The uterus is pyriform in shape and divided into a body and neck. It measures, before the first pregnancy, about

PLATE III.

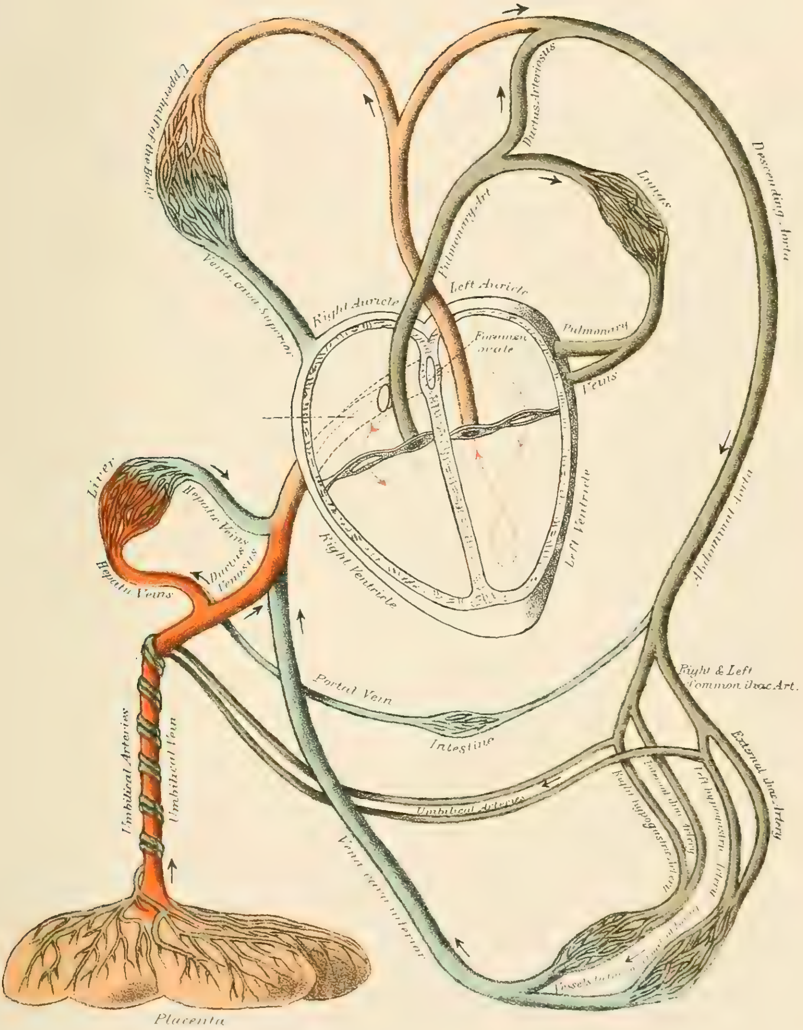
Upper half of the Body
Vena cava superior
Right Auricle
Left Auricle
Foramen ovale
Ductus Arteriosus
Pulmonary Art.
Lungs
Descending Aorta
Pulmonary
Veins
Left Ventricle
Right Ventricle
Liver
Hepatic Veins
Ductus Venosus
Hepatic Veins
Abdominal Aorta
Right & Left Common iliac Art.
Portal Vein
Intestine
External iliac Artery
Left hypogastric Artery
Right hypogastric Artery
Internal iliac Artery
Umbilical Arteries
Umbilical Arteries
Umbilical Vein
Vena cava inferior
Placenta

DIAGRAM OF FŒTAL CIRCULATION.

W Preyer del.

7 cm. in length, 5 cm. in breadth and 2½ cm. in thickness. A frontal section of the uterus shows a central cavity which in the body is triangular in shape, in the neck oval or fusiform (Fig. 349). At the upper angles of the uterus the cavity is continuous with the cavity of each Fallopian tube. At the junction of the body and the neck, the cavity presents a constriction, *the internal os.* The constriction at the end of the neck is known as the *external os.* The walls of the uterus are extremely thick and composed of non-striated muscle-fibers arranged in a very complicated manner. The interior of the uterus is lined by mucous membrane covered with cylindric ciliated epithelial cells, the motion of which is toward the external os. Tubular glands are found in large numbers in the mucous membrane lining the cavity, while racemose glands are found in the mucous membrane lining the neck. Owing to the flattening of the uterus from before backward the walls are almost in contact and the cavity almost obliterated.

The Vagina.—The vagina is a musculo-membranous canal, from 12 to 18 cm. in length, situated between the rectum and bladder. It extends from the surface of the body to the brim of the pelvis, and embraces at its upper extremity the neck of the uterus.

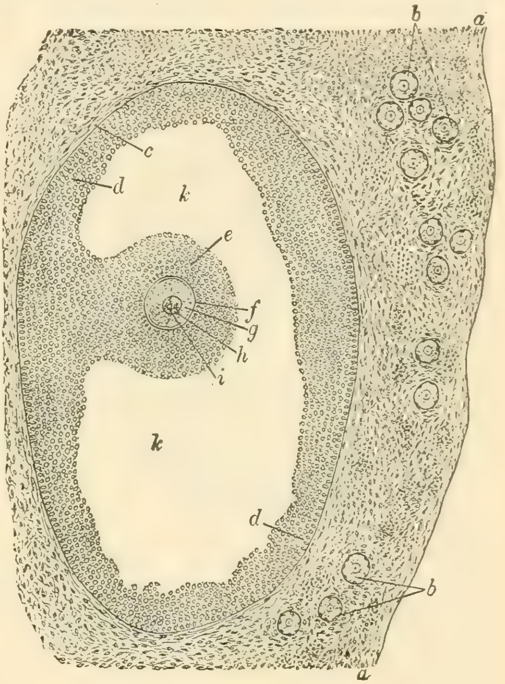

Fig. 347.—Section of Cortex of Cat's Ovary, Exhibiting Large Graafian Follicles. *a.* Peripheral zone of condensed stroma. *b.* Groups of immature follicles. *c.* Theca of follicle. *d.* Membrana granulosa. *e.* Discus proligerus. *f.* Zona pellucida. *g.* Vitellus. *h.* Germinal vesicle. *i.* Germinal spot. *k.* Cavity of liquor folliculi.—(*After Piersol.*)

Ovulation.—After the establishment of puberty a Graafian follicle develops and ripens or matures periodically, usually every twenty-eight days. During the time of maturation the follicle increases in size, from an augmentation of its fluid contents, and approaches the surface of the ovary, where it forms a projection varying from 6 to 12 mm. in size. When maturation is complete the vesicle ruptures, and the ovum and liquid contents are discharged. The ovum, by a mechanism not fully understood, is received by the fimbriated extremity of the Fallopian tube and enters its cavity. The ovum is then transferred through the tube by the peristaltic contraction of its muscle-fibers and by the action of the cilia of its lining epithelium. The time occupied in the transference of the ovum from the ovary to the interior of the uterus has been estimated to be from four to ten days.

Either at the time, or very shortly after, its discharge from the follicle, the ovum, and more especially the nucleus, undergoes a series of histologic changes which eventuates in an extrusion of a portion of the chromatin material. The extruded portions are known as the polar bodies. The non-extruded portion of the chromatin material is known as the female *pronucleus*. The succession of changes which the nucleus undergoes is termed maturation. As the nucleus is regarded as the part of the ovum which transmits parental characteristics it is assumed that the extrusion of a portion of the nuclear material is a means by which an excess of inherited substance is prevented.

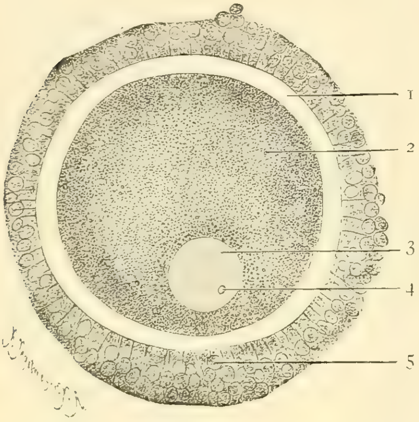

FIG. 348.—OVUM OF A COW. 1. Zona pellucida. 2. Cytoplasm, vitellus. 3. Nucleus, germinal vesicle. 4. Nucleolus, germinal spot. 5. Corona radiata. The radial striation of the zona pellucida can not be seen.—(*Stöhr.*)

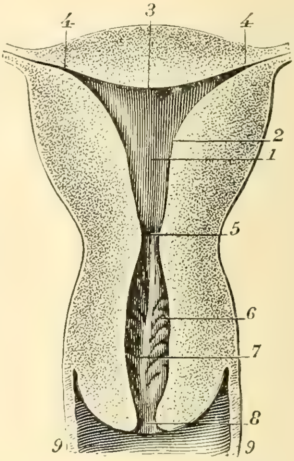

FIG. 349.—FRONTAL SECTION OF THE UTERUS. 1. Cavity of the body. 2, 3. Lateral walls. 4, 4. Cornua. 5. Os internum. 6. Cavity of the cervix. 7. Arbor vitæ of the cervix. 8. Os externum. 9. Vagina.—(*Sappey.*)

Menstruation.—Menstruation is a periodic discharge of blood and mucus from the surface of the mucous membrane of the uterus, and occurs about every twenty-eight days. The duration of the menstrual period extends over four or five days and the amount of blood discharged varies from 180 c.c. to 200 c.c. Menstruation is usually an accompaniment of ovulation, though the latter process may take place independently of the former. It is characterized by both local and systemic changes. The local changes are most marked in the uterus, the mucous membrane of which increases in thickness from a proliferation of the connective tissue and a hyperemic condition of the blood-vessels. Subsequently to these changes the epithelial surface, as well as the more superficial portions of the connective tissue, undergo degeneration and exfoliation, after which the finer blood-vessels rupture and permit of an escape of blood into the uterine cavity. At the end of the menstrual period regenerative changes set in which continue until the normal condition of the mucous membrane is reëstablished.

The Corpus Luteum.—With the rupture of the Graafian follicle there is an effusion of blood into the follicular cavity which soon coagulates, loses its color and assumes the characteristics of fibrin. The walls of the follicle, which have become thickened from the deposition of a reddish-yellow glutinous substance, now become convoluted and undergo a still further hypertrophy, until they encroach upon and almost obliterate the follicular cavity. In a few weeks the mass loses its red color and becomes decidedly yellow, when it is known as the *corpus luteum.* With the continuance of reparative changes this body gradually disappears until at the end of two months nothing remains but a small cicatrix on the surface of the ovary. Such are the changes in the follicle if the ovum has not been impregnated.

The corpus luteum, after impregnation has taken place, undergoes a much slower development, becomes larger, and continues during the entire period of gestation. The difference between the corpus luteum of the unimpregnated and pregnant condition is expressed in the following table by Dalton:

	CORPUS LUTEUM OF MENSTRUATION.	CORPUS LUTEUM OF PREGNANCY.
At the end of three weeks.	Three-quarters of an inch in diameter; central clot reddish; convoluted wall pale.	
One month.	Smaller; convoluted wall bright yellow; clot still reddish.	Larger; convoluted wall bright yellow; clot still reddish.
Two months	Reduced to the condition of an insignificant cicatrix.	Seven-eighths of an inch in diameter; convoluted wall bright yellow; clot perfectly decolorized.
Four months.	Absent or unnoticeable.	Seven-eighths of an inch in diameter; clot pale and fibrinous; convoluted wall dull yellow.
Six months.	Absent.	Still as large as at the end of second month; clot fibrinous; convoluted wall paler.
Nine months.	Absent.	Half an inch in diameter: central clot converted into a radiating cicatrix; external wall tolerably thick and convoluted, but without any bright yellow color.

THE REPRODUCTIVE ORGANS OF THE MALE.

The reproductive organs of the male comprise the testicles, vasa deferentia, vesiculæ seminales, and penis.

The Testicles.—The testicles are oblong glands, about 40 mm. in length, 30 mm. in breadth and 20 mm. in thickness, and contained within the cavity of the scrotum. A section of the testicle (Fig. 350) reveals the presence externally of a dense fibrous membrane, the *tunica albuginea*, and internally a connective-tissue framework consisting mainly of septa, which enter the organ on its posterior aspect at the *mediastinum testis*, passing inward in a diverging manner. The spaces between the septa are occupied by the true gland substance, the seminiferous tubules.

The seminiferous tubules are very numerous, the estimate as to their number varying from 800 to 1000. When unraveled they measure from 30 to 40 cm. in length and 0.3 mm. in diameter. At their peripheral extremities the tubules are very much convoluted, but as they pass toward the mediastinum testis, the convolutions disappear, and after uniting with one another terminate in from twenty to thirty straight tubes, the *vasa recta*, which pass through the mediastinum and form the *rete testis*. At the upper part of the mediastinum the tubules unite to form from nine to thirty small ducts, the *vasa efferentia*, which soon become very much convoluted. After a short course they unite to form a single tortuous tube, about 7 meters in length and 0.4 mm. in diameter, which descends behind the testicle to its lower border. This tube is known as the epididymis. The seminal tubule consists of a basement membrane lined by granular nucleated epithelium.

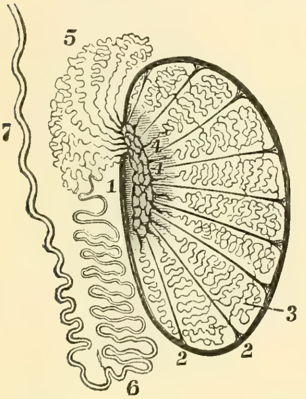

FIG. 350.—DIAGRAM OF A VERTICAL SECTION THROUGH A TESTICLE. 1. Mediastinum testis. 2, 2. Trabeculæ. 3. One of the lobules. 4, 4. Vasa recta. 5. Globus major of the epididymis. 6. Globus minor. 7. Vas deferens.—(*Holden.*)

The *vas deferens*, the excretory duct of the testicle, is about 60 cm. in length and from 2 to 3 mm. in diameter, and extends upward from the epididymis to the inguinal canal, through which it passes into the abdominal cavity and then to the under surface of the base of the bladder, where it unites with the duct of the vesicula seminalis to form the *ejaculatory duct*

The **vesiculæ seminales** are two lobulated pyriform bodies, about 40 mm. in length, situated on the under surface of the bladder. Each vesicula seminalis consists of an external fibrous coat, a middle, muscular coat, and an external mucous coat. The mucous coat contains a number of small tubular albumin-producing glands which secrete a characteristic fluid.

The *ejaculatory duct*, formed by the union of the vas deferens and the duct of the *vesicula seminalis*, opens into the prostatic portion of the urethra (Fig. 351).

The **prostate gland** is a musculo-glandular mass situated at the posterior extremity of the urethra. It contains a large number of tubules, more or less branched and convoluted, and lined by columnar epithelium. They secrete a fluid which is poured into the urethra at the time of the ejaculation of semen.

The **penis** consists of three parts: the *corpus spongiosum* below, through which passes the urethra, and the two *corpora cavernosa*, one on either side and above. The corpus spongiosum terminates anteriorly in a conic-shaped structure, the *glans penis;* the corpora cavernosa consist externally of a fibrous investment and internally of erectile tissue. These bodies are abundantly supplied with blood, which after entering their substance by the arteries, passes into sinuses or reservoirs, from which it is carried away by veins. These vessels pass to the dorsum of the penis and unite to form a large vein by which the blood is returned to the general circulation. By virtue of the erectile tissue in the corpora cavernosa the penis becomes erect and rigid when the blood supply is increased. This takes place in response to peripheral stimulation or emotional states, or both combined. When these conditions are established nerve impulses pass outward through nerves, the *nervi erigentes*, which have their origin in the lumbar region of the spinal cord, and bring about an active dilatation of the arteries and a relaxation of the non-striated muscle-fibers in the corpora cavernosa. With these events there is a rapid influx of blood and a distention and an erection of the organ. This condition is furthered and maintained by a partial compression of the dorsal vein by the fibrous capsule.

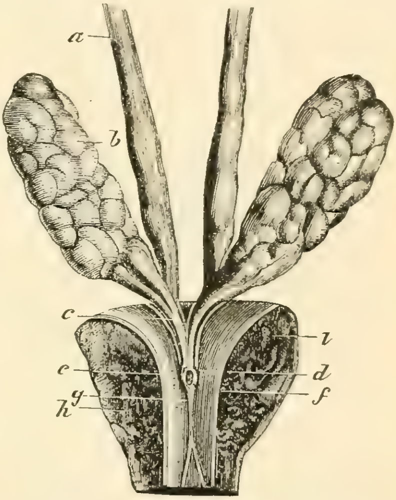

FIG. 351.—VAS DEFERENS, VESICULÆ SEMINALES, AND EJACULATORY DUCTS. *a.* Vas deferens. *b.* Seminal vesicle. *c.* Ejaculatory duct. *d.* Termination of the ejaculatory duct. *e.* Opening of the prostatic utricle. *f, g.* Veru montanum. *h, l.* Prostate.—(*Liégeois.*)

Semen.—The semen is a complex fluid composed of the secretions of the testicles, the vesiculæ seminales, the prostatic tubules, and urethral glands. It is grayish-white in color, mucilaginous in consistence, characteristic in odor, and somewhat heavier than water. In response to appropriate stimulation the muscle-fibers in the walls of the vasa deferentia, vesiculæ seminales, and prostatic tubules contract and discharge their contents into the urethra, from which they are forcibly ejected by the rhythmic contraction of the ejaculatory muscles, the *ischio-* and *bulbo cavernosi.* The amount of semen discharged at each ejaculation varies from 1 to 5 c.c.

Spermatozoa.—The spermatozoa are peculiar morphologic elements which arise within the seminiferous tubules as a result of complex histologic changes in the lining epithelium. An adult spermatozoön consists of a conoid slightly flattened head, from the posterior part of which there projects a short straight rod, provided with a long filamentous tail or cilium and an end-piece (Fig. 352). The head contains a nucleus of chromatin material. The total length of a spermatozoön varies from 50 to 80 micromillimeters. The characteristic physiologic feature of spermatozoa is incessant locomotion when in a suitable medium. So long as they are confined to the vas deferens they are quiescent, but with their advent into the vesicula seminalis and dissemination in its contained fluid, they become extremely active and move around with considerable rapidity. The power of locomotion depends on the possession of the tail which, by lashing the surrounding fluid now in this and now in that direction, propels the head from place to place. The vitality of spermatozoa is such as to enable them to retain their physiologic activities in the uterus for more than eight days.

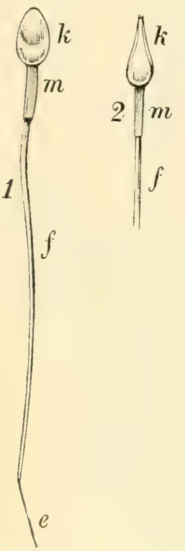

FIG. 352.—HUMAN SPERMATOZOON. 1. Front view, 2, side view, of the head. *k.* Head. *m.* middle piece. *f.* Tail. *e.* Terminal filament.—(*After Retzius.*)

The development of spermatozoa from testicular cells as observed in lower animals indicates that each cell gives rise to four embryonic forms—spermatids—which subsequently develop into adult spermatozoa. In this process the primary nuclear chromatin undergoes a division, so that each spermatozoön receives but a fractional amount. The changes by which this condition is brought about are comparable to the changes exhibited by the ovum, and have for their result a reduction in the quantity of hereditary substance to be transmitted.

Fecundation.—Fecundation is the union of the spermatozoön (the sperm-cell) with the ovum (the germ-cell) and takes place in the great majority of instances in the Fallopian tube. After the introduction of the spermatozoa into the vagina during the act of copulation, they soon begin to pass upward, into and through, the uterine cavity and out into the Fallopian tube, where they accumulate in large numbers and retain their vitality for some days. The migration is effected by the propelling power of the filamentous tail.

From observations made on the behavior of the spermatozoa toward the ovum in lower animals, and on the manner by which their union is effected, the inference may be drawn that a similar procedure takes place in mammals. In lower animals the spermatozoa on approaching an ovum take on increased activity, swimming around it in all directions and apparently seeking a point of entrance. In fish and molluscs the zona pellucida presents a distinct opening, the *micropyle*, through which the spermatozoön passes. Inasmuch as the mammalian ovum is devoid of such an opening, the mechanism of entrance of the spermatozoön is not clearly understood. Notwithstanding their enormous numbers it is generally believed that but a single spermatozoön effects an entrance into the ovum. With the accomplishment of this, however, the spermatozoön loses its vitality, after which the body and tail disappear. The head, which in this instance also is the transmitter of the inherited material, advances to meet and unite with the nucleus of the ovum. A series of histologic changes now arise, which eventuate in the production of a new cell, a parent cell, possessing all the features of cell structure and the physiologic activities and characteristics of both ancestral cells. From this parent cell the new being develops through successive division, multiplication, and differentiation of cells.

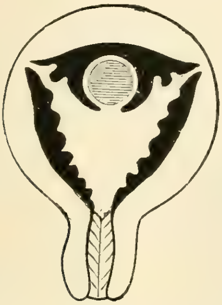

FIG. 353.—IMPREGNATED UTERUS, WITH FOLDS OF DECIDUA GROWING UP AROUND THE EGG. The narrow opening, where the folds approach each other, is seen over the most prominent portion of the egg.—(*Dalton.*)

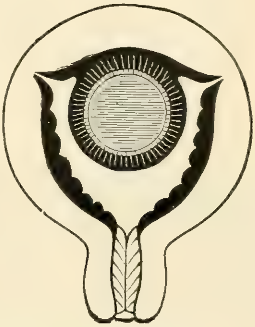

FIG. 354.—IMPREGNATED UTERUS; showing the connection between the villosities of the chorion and the decidual membranes.—(*Dalton.*)

The Fixation of the Ovum.—If the ovum is to develop into a new being it is essential that it be retained within the cavity of the uterus. This is accomplished by the development of specialized structures on the surface of the uterine mucosa and on the surface of the ovum. With the fertilization of the ovum, the mucous membrane of the uterus takes on an increased growth; it becomes hypertrophied and vascular, and develops small elevations known as villi. Inasmuch as this membrane is detached and discharged at the birth of the fetus, it is known as the *decidua vera*. With the fertilization of the ovum, the zona pellucida or radiata also develops villosities, and as it passes from the Fallopian tube into the uterus the villi interdigitate, and its further progress is retarded. (Figs. 353 and 354.) In a short time a portion of the decidua vera grows up on all sides and encloses the ovum. Its retention is thus secured. That portion of the decidua which grows around the ovum is termed the *decidua reflexa;* while the portion to which the ovum attaches itself is termed the *decidua serotina*, and is of interest for the reason that it becomes the seat of development of the placenta, the organ by which the fetus is nourished. As development advances the decidua reflexa also increases in size and extent, and about the end of the fourth month comes into contact with the decidua vera, with which it ultimately fuses.

DEVELOPMENT OF FETAL ACCESSORY STRUCTURES.

Segmentation of the Ovum.—Shortly after the formation of the parent cell, segmentation of the nucleus and cytoplasm takes place in accordance with karyokinetic methods. The two new cells thus formed undergo a similar division into four, the four into eight, the eight into sixteen, and so on until the space within the zona pellucida is completely filled with a large number of small cells, each possessing the characteristic cell structures. The peripheral cells then arrange themselves in the form of a membrane, and as they are, at the same time, subjected to mutual pressure they assume a polyhedral shape, and give to the membrane a mosaic appearance (Fig. 355). The central cells then undergo liquefaction. At some point on the inner surface of the membrane, cells accumulate which by their division and multiplication form a second membrane. The two together are known as the external and internal blastodermic membranes.

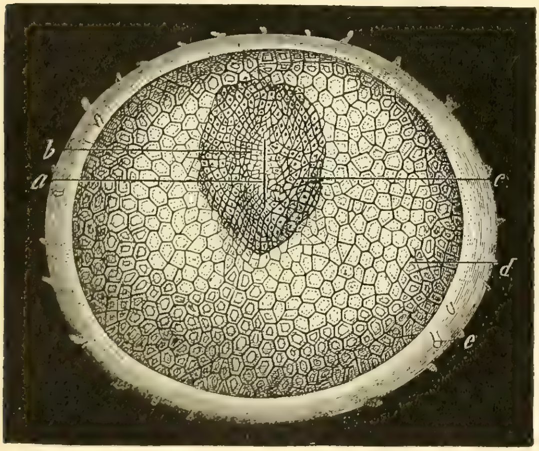

FIG. 355.—PRIMITIVE TRACE OF THE EMBRYO. *a.* Primitive trace. *b.* Area pellucida. *c.* Area opaca. *d.* Blastodermic cells. *e.* Villi beginning to appear on the surface of the zona pellucida.—(*Lugois.*)

Germinal Area.—At about this period there is an accumulation of cells at a certain spot in the substance of the blastodermic membranes which marks the position of the future embryo. This spot, at first circular, soon becomes elongated. A slight indentation now develops into what is known as the *primitive trace.* Around this area there is a clear space, the *area pellucida,* which is in turn surrounded by a darker region, the *area opaca.* The primitive trace soon disappears and the area pellucida becomes guitar-shaped. A second groove, the *medullary groove,* is now formed, which develops from before backward and becomes the neural medullary canal.

Blastodermic Membranes.—The embyro, at this period, consists of three layers—viz., the external and the internal blastodermic membranes and a middle membrane formed by a genesis of cells from their internal surfaces. These layers are known from without inward as the epiblast, mesoblast, and hypoblast.

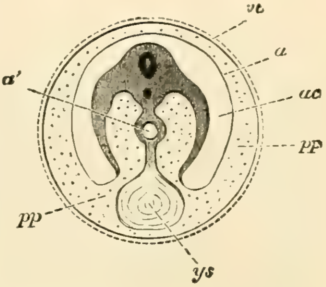

Fig. 356.—Diagram Representing the Relation of Primary Structures in a Developing Chicken; Vertical Transverse Section. The medullary groove and chorda dorsalis are seen in section; the alimentary canal pinched off from the yolk-sac is completely closed. *a.* Amnion. *a, c.* Amniotic cavity filled with amniotic fluid. *pp.* Space between amnion and chorion continuous with the pleuro-peritoneal cavity inside the body. *vt.* Vitelline membrane, or zona pellucida. *ys.* Yolk-sac, or umbilical vesicle.—(*Foster and Balfour.*)

The *epiblast* gives rise to the central nerve system, the epidermis and its appendages, and the primitive kidneys.

The *mesoblast* gives rise to the dermis, muscles, bones, nerves, blood-vessels, sympathetic nerve system, connective tissue, the urinary and reproductive apparatus, and the walls of the alimentary canal.

The *hypoblast* gives rise to the epithelial lining of the alimentary canal and its glandular appendages, the liver and pancreas, and the epithelium of the respiratory tract.

Dorsal Laminæ.—As development advances, the true medullary groove deepens, and there arise two longitudinal elevations of the epiblast—the *dorsal laminæ,* one on either side of the groove—which grow up, arch over, and unite so as to form a closed tube, the primitive central nerve system.

The Chorda Dorsalis.—Just beneath the neural canal there arises a group of hypoblastic cells which arrange themselves in the form of a cylindric rod, which marks out the position of the future bony axis of the body. This rod is known as the chorda dorsalis or notochord.

Primitive Vertebræ.—On either side of the neural canal the cells of the mesoblast undergo a longitudinal thickening, which develops and extends around the neural canal and the chorda dorsalis, and forms the arches and the bodies of vertebræ. They become divided transversely into segments.

The *mesoblast* now separates into two layers: the external, joining with the epiblast, forms the *somatopleura;* the internal, joining with the hypoblast, forms the *splanchnopleura;* the space between them constitutes the *pleuro-peritoneal* cavity (Fig. 356).

Visceral Laminæ.—The walls of the pleuro-peritoneal cavity are formed by a downward prolongation of the somatopleura (the *visceral laminæ*), which, as they extend around in front, pinch off a portion of the yolk-sac (formed by the splanchnopleura), which becomes the primitive alimentary canal; the lower portion, remaining outside of the body cavity, forms the *umbilical vesicle.*

The Fetal or Embryonic Membranes.—With the appearance of the visceral laminæ two membranes develop in succession, both of which play an important part in the subsequent life of the embryo. These are known as the amnion and the allantois.

The *amnion* is formed by folds of the epiblast and the external layer of the mesoblast rising up in front, behind, and at the sides. These folds gradually extend over the back of the embryo to a certain point where they meet, coalesce, and enclose a cavity known as the *amniotic cavity.* The membranous partition between the folds is absorbed, after which the outer layer recedes and becomes blended with the primitive enveloping membrane of the ovum and thus assists in the formation of the *chorion*—the external covering of the embryo.

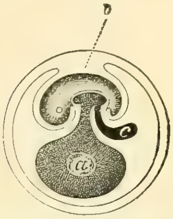

FIG. 357.—DIAGRAM OF FECUNDATED EGG. *a.* Umbilical vesicle. *b.* Amniotic cavity. *c.* Allantois.—(*Dalton.*)

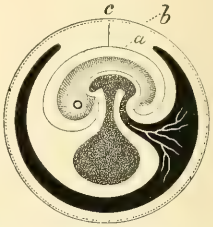

FIG. 358.—FECUNDATED EGG WITH ALLANTOIS NEARLY COMPLETE. *a.* Inner layer of amniotic fold. *b.* Outer layer of ditto. *c.* Point where the amniotic folds come in contact. The allantois is seen penetrating between the outer and inner layers of the amniotic folds.—(*Dalton.*)

The cavity enclosed by the amnion is at first quite small, but soon enlarges from the accumulation of a clear, transparent fluid, the *amniotic fluid.* It gradually increases in amount up to the latter period of gestation, when its volume reaches about one liter. This fluid is derived mainly from the blood, as it contains albumin, sugar, fatty matter, and inorganic salts. Traces of urea indicate that some of its constituents are derived from the embryo itself.

The *allantois* is primarily a pouch or diverticulum which develops from the posterior portion of the alimentary canal. As it develops it enlarges, and in its growth inserts itself between the two layers of the amnion, coming into contact more especially with the external layer.

It finally completely surrounds the embryo, after which its edges become fused together (Figs. 357 and 358).

The allantois is of especial interest and importance, as it is the means by which the blood of the embryo is brought into relation with the blood of the mother. As it develops, two arteries, *the hypogastrics*, one from each internal iliac, pass out of the abdominal cavity within the walls of the allantois, and follow it in its course around the embryo. The ultimate branches of these arteries penetrate the villous processes which develop on the surface of the chorion and which take part in the formation of the placenta. A single large vein emerges from the placenta and returns the blood to the embryo. In its course it winds around the arteries in a spiral manner a number of times. These vessels—the umbilical arteries and vein—are enclosed by the walls of the allantois and amnion, and together constitute the umbilical cord which at the end of gestation is about 60 cm. in length. (Figs. 359, 360).

The Chorion.—The chorion, the external investment of the embryo, is formed by the fusion of the primitive egg membrane—the zona pellucida—the external layer of the amnion, and the allantois. Very early in development its external surface becomes covered with homogeneous, granular, club-shaped processes, which by continued budding and growth, give to the membrane a shaggy appearance. At about the end of the second month these processes begin to atrophy and disappear from the surface of the chorion, with the exception of that portion which is in contact with the decidua serotina. At this point the processes or villi continue to grow and develop, and insert themselves more deeply into the mucous membrane. Corresponding processes from the mucous membrane insert themselves between the villi of the chorion, which by their growth and fusion secure, among other things, the retention of the embryo.

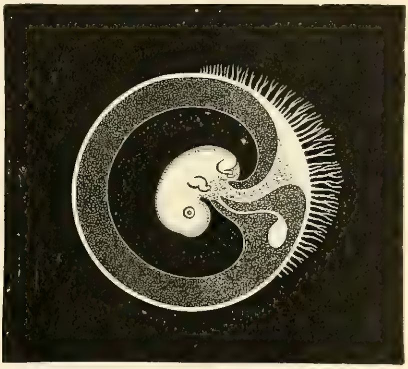

FIG. 359.—HUMAN EMBRYO AND ITS ENVELOPES AT THE END OF THE THIRD MONTH.

The Nutrition of the Embryo.—Coincidently with the development of the amnion, allantois, and chorion, there arises within the body of the embryo the early forms of many, if not all, of the future viscera. The nutritive material required for their growth is partly contained within the umbilical vesicle lying without the body cavity. That this material may be utilized, blood-vessels emerge from the body and ramify within the walls of the vesicle. The capillaries to which these vessels give rise come into close relation with and absorb the food material, after which it is carried by veins to the heart, by which it is distributed to all parts of the embryo. These vessels are collectively known as the *omphalo-mesenteric arteries and veins.* This primitive or vitelline circulation is of short duration in mammals, as the nutritive material in the vesicle is small in amount and is soon exhausted. In birds, however, it is of primary importance. The main supply of nutritive material, however, is derived from the mother by means of a highly developed and specialized organ—

The Placenta.—Of all the embryonic structures the placenta is the most important. It is formed by the end of the third month, after which it gradually increases in size up to the end of the eighth month, by which time it is fully developed. It then measures from 18 to 24 cm. in diameter and weighs from 400 to 600 grams. It is most frequently situated at the upper and back part of the uterine cavity. Though exceedingly complex in structure it consists essentially of two portions, a fetal and a maternal.

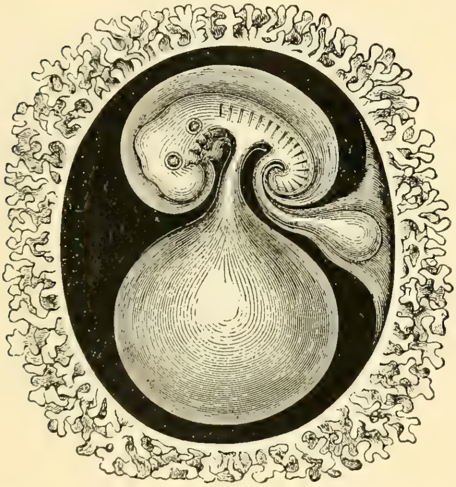

FIG. 360.—HUMAN EMBRYO, WITH AMNION AND ALLANTOIS, IN THE THIRD WEEK. There are as yet no limbs; the embryo and its appendages are surrounded by the tufted chorion.—(*Haeckel.*)

The *fetal* portion consists primarily of those villi on the chorion in relation with the decidua serotina. These structures gradually increase in size and number, and receive the ultimate branches of the umbilical arteries. The *maternal* portion consists primarily of the decidua serotina. As gestation advances the chorionic villi rapidly increase in size and number, and receive the branches of the umbilical arteries. At the same time the decidua serotina becomes hypertrophied and vascular. With the continued growth and development of these two structures they gradually fuse together and finally become inseparable. In accordance with the needs of the embryo, the decidua serotina and its contained blood-vessels undergo certain histologic changes which result in the formation of large cavities, sinuses, or lakes, into which the blood of the uterine vessels is emptied. Coincidently the villi of the chorion grow and give off numerous branches, which project themselves in all directions into the blood of uterine sinuses (Figs. 361, 362). As the placenta develops, the structures separating the blood of the mother from that of the child gradually become modified until they are represented by a thin cellular or homogeneous membrane. The conditions now are such as to permit of a free exchange of material between the mother and child. Whether by osmosis or by an act of secretion, the nutritive materials of the maternal blood pass through the intervening membrane into the fetal blood on the one hand, while waste products pass in the reverse direction into the maternal blood on the other hand. Inasmuch as oxygen is absorbed and carbon dioxid exhaled by the same structures, the placenta is to be regarded as both a digestive and a respiratory organ. So long as these exchanges are permitted to take place in a normal manner the nutrition of the embryo is secured.

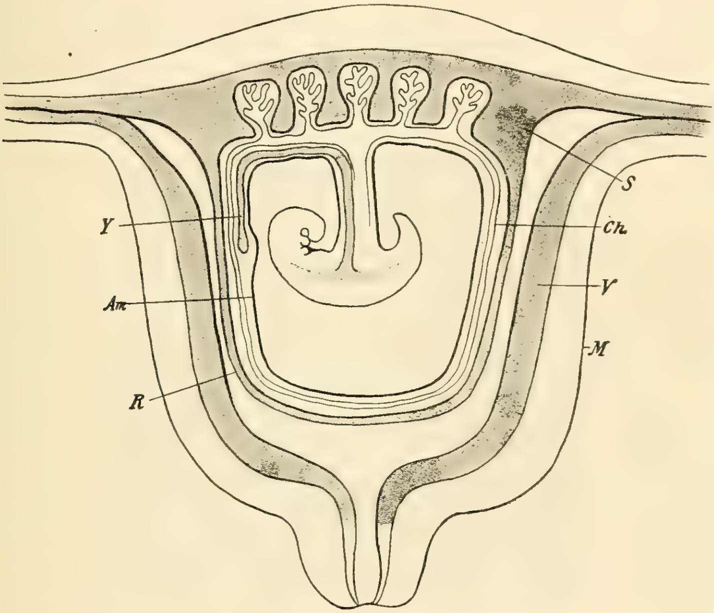

FIG. 361.—DIAGRAM SHOWING THE RELATIONS OF THE FETAL MEMBRANES. *Am.* Amnion. *Ch.* Chorion. *M.* Muscle wall of uterus. *R.* Decidua reflexa. *S.* Serotina. *V.* Decidua vera. *Y.* Yolk stalk.—(*McMurrich.*)

The Fetal Circulation.—The composition of the blood as well as the course it pursues through the heart and vascular apparatus presents peculiarities which have arisen in consequence of the necessity of obtaining nutritive material through the placenta and the almost impervious condition of the pulmonary capillaries. On returning from the placenta, the blood in the umbilical vein is relatively rich in nutritive material and scarlet red in color from the presence of oxygen. As it passes into the abdominal cavity a portion of the blood is directed by the *ductus venosus* into the vena cava, while another portion is emptied into the branches of the portal vein, by which it is distributed to the liver and from which it emerges by the hepatic veins and poured into the vena cava. The blood in the vena cava is thus a mixture of venous blood from the lower extremities and liver, and oxygenated blood from the placenta. After its discharge into the right auricle the blood is directed by a fold of the lining membrane, the Eustachian valve, through an opening in the interauricular septum, the *foramen ovale*, into the left auricle. It then flows through the auriculo-ventricular opening into the left ventricle, thence into the aorta, and by its branches is distributed to all parts of the body.

The blood from the head and upper extremities is emptied by the superior vena cava into the right auricle, but as it passes in front of the Eustachian valve, it flows directly into the right ventricle and then into the pulmonary artery. On account of the unexpanded condition of the lungs and the almost impervious condition of the pulmonary capillaries, but a small portion of the blood passes through them, while the larger portion by far passes into the aorta directly through a duct, *the ductus arteriosus*, which enters at a point below the origin of the left carotid and subclavian arteries. A comparison of the blood distributed to the head and upper extremities, with that distributed to the lower extremities, will show a larger percentage of nutritive material and oxygen in the former than in the latter, a fact which has been offered as an explanation of the more rapid growth of the upper half of the body. As the blood passes through the aorta, a portion is directed from the main current by the hypogastric and umbilical arteries to the placenta, where it loses carbon

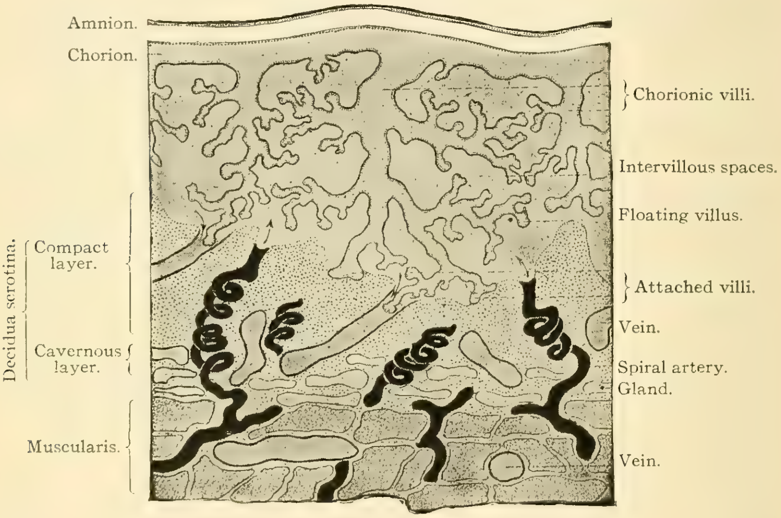

FIG. 362.—DIAGRAM OF HUMAN PLACENTA AT THE CLOSE OF PREGNANCY.—(*Schäper.*)

dioxid and gains oxygen, and changes in color from a bluish red to a scarlet red.

Parturition.—At the end of gestation—approximately 280 days from the time of conception—a series of changes occur in the uterine structures which lead to an expulsion of the child, the placenta, and decidua vera. To this process in its entirety the term parturition is given. At this time, from causes not clearly defined, the uterine walls begin to exhibit throughout their extent a series of slight contractions which are somewhat peristaltic in character; these contractions, which gradually increase in frequency and vigor, bring about a dilatation of the internal os and a descent of the membranes into the cervical canal. The pressure exerted by these membranes during the time of the contraction materially assists in the relaxation of the circular fibers and a dilatation of the external os. When the dilatation has so far advanced that the diameter of the external os attains a measure of 7 or 8 cm., the tension of the membranes becomes sufficiently great to lead to their rupture and to a partial escape of the amniotic fluid. With this event, the presenting part of the child, usually the head, descends into the cervical canal. After a short period of rest the uterine contractions return and rapidly increase in vigor and duration. As a result of the pressure thus exerted from all sides on the body of the child, the head gradually descends into the vagina and finally emerges through the vulva to be followed in a short time by the expulsion of the trunk and limbs, and a discharge of the remaining amniotic fluid. With the expulsion of the child the uterine contractions cease for a period of ten or fifteen minutes, when they again recur, with the result of detaching the placenta and expelling it into the vagina. It is then removed by the coöperative action of the abdominal and perineal muscles. The hemorrhage which would naturally occur with the detachment of the placenta and the laceration of the maternal vessels is prevented by the firm continuous contraction of the uterine walls, by which the vessels are compressed and permanently closed.

The Establishment of Inspiration and the Adult Circulation.—After the birth of the child and the detachment of the placenta, there speedily occurs a decrease in the quantity of oxygen and an increase in the quantity of carbon dioxid in the blood, a condition which causes a discharge of nerve energy from the inspiratory center, a contraction of the inspiratory muscles, an expansion of the thorax, and an inflow of air into the lungs.

In the later months of intrauterine life the vascular apparatus undergoes certain anatomic changes which favor the transition from the placental to the adult circulation. Thus the *ductus venosus* contracts, and shunts a larger volume of blood into and through the liver; the Eustachian valve diminishes in size and at the time of birth has almost disappeared; a membranous fold grows upward and backward from the edge of the foramen ovale on the left side; the *ductus arteriosus* also contracts. With the first inspiration and the expansion of the lungs, the blood which enters the pulmonary artery passes through the pulmonary capillaries in large volume and is returned by the pulmonary veins to the left auricle. The entrance of the blood into this cavity presses the membranous fold against the margins of the foramen ovale and thus prevents the further flow of blood from the right auricle. The blood entering the right auricle by the inferior vena cava now flows into the right ventricle, which is favored by the small size of the Eustachian valve. The foramen ovale is permanently closed at the end of a week or ten days; the ductus arteriosus at the end of four days. The umbilical vein and ductus venosus, at the end of four or five days, have also become almost impervious from the contraction of their walls. The hypogastric arteries remain open and carry blood to the walls of the bladder.

Lactation.—As pregnancy advances the mammary glands increase in size, partly from a deposition of fat and connective tissue and partly from a multiplication of the secreting acini. The lining epithelial cells at the same time increase in size, and toward the end of pregnancy begin to exhibit functional activity. At the time of birth, or within a day or so after birth, the acini are filled with a fluid which in its qualitative composition resembles milk and is known as *colostrum.* It is distinguished from milk more especially in the fact that it contains in large quantity a proteid which coagulates on boiling, and certain inorganic salts which have a laxative effect on the newborn child. Normal lactation and the phenomena which accompany it are fully established by the end of the second or third day.

The composition of milk and the mechanism of its production have been stated in the chapter on Secretion.

Physiologic Activities of the Embryo.—During intrauterine life the evolution of structure is accompanied by an evolution of function. The relatively simple and uniform metabolism of the undifferentiated blastodermic membranes gradually increases in complexity and variety, as the individual tissues and organs make their appearance and assume even a slight degree of functional activity. As to the periods at which different organs begin to functionate, but little is positively known.

The primitive heart, in all probability, begins to pulsate very early, as in an embryo from fifteen to eighteen days old and measuring but 2.2 mm. in length, Coste found the amnion, the allantois, the omphalo-mesenteric vessels, and the two primitive aortæ developed. In the earlier weeks, all products of metabolism are doubtless eliminated by the placental structures; but as metabolism increases in complexity the liver and kidney assume excretory activity. Thus, at the end of the third month the intestine contains a dark, greenish, viscid material—meconium—composed of bile pigments, bile salts, and desquamated epithelium; the amniotic fluid, as well as the fluid within the bladder, contains urea at the end of the sixth month, indicating the establishment of both hepatic and renal activity. Contractions of the skeletal muscles of the limbs begin about the fifth month, from which it may be inferred that the mechanism for muscle activity, viz., muscles, efferent nerves, and spinal centers, has become anatomically developed and associated, and capable of coördinate activity. These contractions are, in all probability, automatic or autochthonic in character due to stimuli arising within the spinal centers. The remaining organs remain more or less inactive.

After birth, with the first inspiration and the introduction of food into the alimentary canal, the physiologic mechanisms which subserve general metabolism begin to functionate and in the course of a week are fully established. At this time the cardiac pulsation averages about 135 a minute; the respiratory movements vary from 30 to 35 a minute, and are diaphragmatic in type; the urine, which was at first scanty, is now abundant and proportional to the food consumed; the digestive glands are elaborating their respective enzymes, digestion proceeding as in the adult. The hepatic secretion is active and the lower bowel is emptied of its contents; the coördinate activities of the nerve-, muscle-, and gland-mechanisms are entirely reflex in character. Psychic activities are in abeyance by reason of the incomplete development of the cerebral mechanisms.

APPENDIX.

PHYSIOLOGIC APPARATUS.

The study of the physical and physiologic properties of muscles and nerves necessitates the employment of some stimulus which, when applied to either tissue, will call forth a contraction of the muscle, or the development of a nerve impulse in the nerve. The most convenient stimulus is electricity, for the reason that, with appropriate apparatus, its intensity and duration can be graduated with the utmost nicety. Moreover, it does not destroy the tissues, as do many chemic, physical, and mechanic stimuli.

It is therefore necessary that the student should have a practical acquaintance with those appliances by means of which electricity is generated, applied and controlled.

The **electric cell** is an apparatus composed of different elements, which, by virtue of chemic actions taking place among them, generate and conduct electricity. In its simplest form an electric cell consists of two metals—zinc and copper, or carbon, or platinum, etc., immersed in an exciting fluid, usually dilute sulphuric acid (Fig. 363).

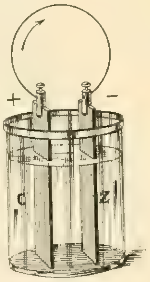

Fig. 363.—An Electric Cell.

The zinc element is the one acted on chemically by the sulphuric acid, and at the expense of which the electricity is maintained. It is known as the generating element. The copper is the collecting and conducting element.

With the immersion of these elements in a solution of H_2SO_4 a chemic action at once takes place between the zinc and the acid, with the formation of zinc sulphate and the liberation of hydrogen, as expressed in the following formula:

$$Zn + H_2SO_4 = ZnSO_4 + H_2.$$

The zinc sulphate passes into the solution, while the hydrogen accumulates on the surface of the copper element.

As all chemic action is accompanied by the development of electricity, it can be shown by appropriate means that this is the case at the surface of the zinc. Such a combination is the means of establishing *a difference of potential between two points;* the point of highest potential being the surface of the zinc or the positive element, the point of lowest potential being the copper or the negative element.

So long as the elements remain unconnected there is no movement of electricity, no current.

If the ends of the elements projecting beyond the fluid are connected by a copper wire, a pathway or circuit is established, and a movement of the electricity takes place. As electricity flows from the point of high to the point of low potential, it follows that inside the cell the current flows from the zinc to the copper, and outside the cell from the copper to the zinc. Such a current is termed *a continuous*, *a galvanic* or *a voltaic current.* Inasmuch as there is a progressive fall in potential between the highest and lowest points, it follows that any two points in the circuit will exhibit a similar difference of potential. For this reason the projecting end of the copper element is at a higher potential than the projecting end of the zinc element. The end of the copper is, therefore, termed the positive, + pole or *anode*, the end of the zinc the negative,—pole or *kathode.*

Electric Units.—Owing to the difference of the electric potential in the cell, the electricity leaves the cell under a certain degree of pressure, termed the "electro-motive force." As it passes through the circuit it meets with resistance, the amount of which will depend on the nature of the circuit material, its length, and the area of its cross-section. In accordance with the resistance will depend the quantity of electricity that a given electro-motive force will press through in a unit of time. The strength of the current will therefore not depend entirely on the electro-motive force, but, rather, on the ratio between the electro-motive force and the resistance.

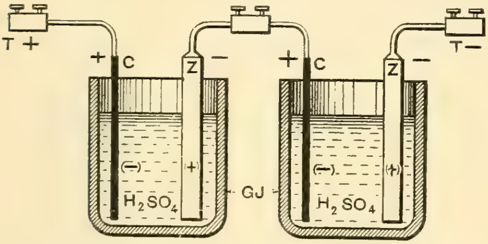

FIG. 364.—TWO SIMPLE ELECTRIC CELLS JOINED IN SERIES. C. Copper. Z. Zinc.

For the measurement of electric quantities, a system of units has been devised. The unit of electro-motive force is the volt; the unit of resistance is the ohm, *i. e.*, the resistance offered by a column of mercury 106.3 cm. long and 1 sq. mm. in section at 0° C.; the unit of quantity is the coulomb; the unit of time is one second. One volt is the electro-motive force which, when steadily applied, will press through a resistance of one ohm, one coulomb of electricity in one second of time yielding a current strength of one ampere.

This relation may be expressed in the following formula, Ohm's law:

$$\text{C (current strength)} = \frac{\text{Electro-motive force (E. M. F.)}}{\text{Resistance (R)}} \text{ or Ampere} = \frac{\text{Volt}}{\text{Ohm}}$$

In practical work it is often necessary to increase the strength of the current. This is done by uniting two or more cells in series, *i. e.*, uniting the copper of one cell to the zinc of a second, and so on (Fig. 364). If the resistance remains the same the total voltage is that of one cell multiplied by the number of cells united.

The cell as above described cannot maintain a current of constant strength for any length of time, for the following reasons:

1. The sulphuric acid solution, in consequence of its chemic action, soon becomes nothing more than a saturated solution of zinc sulphate, after which its chemic activity ceases. The current, therefore, soon diminishes in strength.

2. The accumulation of hydrogen bubbles on the surface of the copper hinders the passage of the electricity. In a short time they develop a current in the opposite direction, which also tends to weaken the original current. This action is termed polarization of the elements.

Cells of this character are not suited for physiologic work, in which constancy in the strength of the current is absolutely necessary. To overcome these disadvantages, cells have been devised which are less violent in action, which prevent polarization, and which maintain a current of constant strength for a long period of time. One of the most generally used for physiologic purposes is—

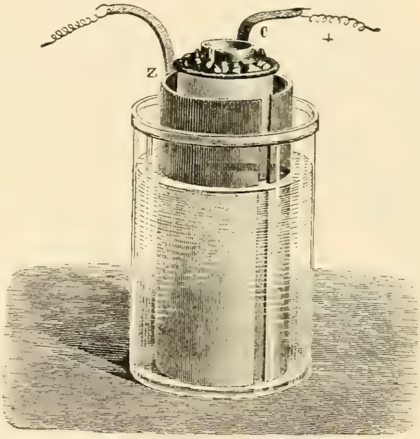

FIG. 365.—DANIELL CELL.

The **Daniell cell.** This consists of a porous cup containing a saturated solution of $CuSO_4$, copper sulphate, in which is immersed a copper plate or rod. This combination is placed in a glass vessel containing a solution of H_2SO_4 (1:15). In this solution is immersed a roll of sheet zinc (Fig. 365). Each of the plates is provided with a binding screw. When the cell is in action the sulphuric acid attacks the zinc, forming zinc sulphate, and liberates hydrogen; the cup being porous, the hydrogen passes into the copper sulphate solution, where it combines with the sulphuric acid radicle, and liberates metallic copper. Polarization of the copper is thus prevented. The metallic copper is deposited on the copper plate, which is thus kept bright. The copper sulphate solution is kept at the point of saturation by packing around the copper cylinder a quantity of the crystals of the salt. The sulphuric acid passes back into the porous cup, to take the place of that used. This cell is remarkably constant for these reasons, and well adapted for physiologic as well as other purposes where a current of uniform strength is necessary.

The projecting ends of the copper and zinc plates are termed respectively the positive pole or anode, and the negative pole or kathode. The electro-motive force of a Daniell cell is practically 1 volt; but when the two poles are connected by a wire of 1 ohm resistance, the current strength will be less than 1 ampere, possibly only 0.7, owing to the resistance offered to the flow of electricity by the fluids between the zinc and the copper. In all measurements, the internal resistance of the cell must be taken into consideration.

The Dry Cell.—The commercial dry cell is a convenient source of electricity for general laboratory work. It consists of a cup of zinc, the inner surface of which is covered over with a thick layer of a paste of plaster-of-Paris, saturated with ammonium chlorid. In the center of the cup there is a rod of carbon. Surrounding this rod and occupying the space between it and the plaster-of-Paris paste, is a mixture of manganese dioxid and charcoal. The upper surface of the cell is sealed to prevent evaporation. The electricity is generated at the surface of the zinc cup by the chemic action of the chlorin which arises from the dissociation of the ammonium chlorid. When the plates are united by a conjunctive wire the current within the cell flows from the zinc (the positive element) to the carbon (the negative element), and without the cell from the carbon (the positive pole) to the zinc (the negative pole).

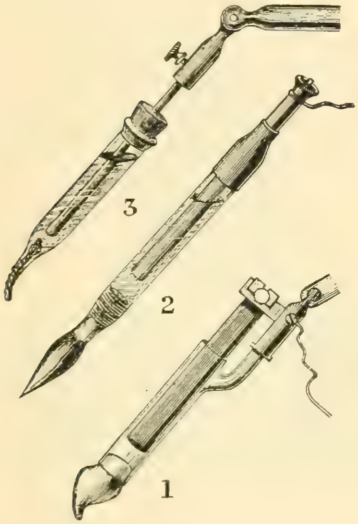

FIG. 366.—NON-POLARIZABLE ELECTRODES. 1. Du Bois-Reymond's. 2. Von Fleischl's. 3. d'Arsonval's.

Leads.—By means of insulated wires attached to the poles of a cell, the electricity may be conducted from the cell and used for exciting or stimulating purpose. As the wires thus become practically prolongations of the plates their ends become the corresponding poles. In experimental work the ends of the wires are provided with special devices, termed—

Non-polarizable electrodes. The necessity for the employmen of such electrodes arises from the fact that when the ends of the wires from a cell are placed in direct contact with the tissues chemic changes are produced in a short time, which lead to their polarization. As a result, a current opposite in direction to that of the cell is developed, which tends to weaken or neutralize it. This polarization current vitiates the result of many experiments made with highly irritable tissue such as nerve-tissue. Whether for stimulating purposes or for the purpose of detecting the existence of electric currents in living tissues, it is essential that the electrodes used shall be non-polarizable. The earliest electrodes of this character were made by du Bois-Reymond and were based on the fact discovered by Regnault that a strip of chemically pure zinc or amalgamated zinc (Matteucci) immersed in a saturated solution of zinc sulphate would not polarize. One form made by du Bois-Reymond is shown in Fig. 366. It consists of a flattened glass tube attached to a universal joint and supported by an insulated brass stand. The lower end of the tube is closed with kaolin or China clay made into a paste with a 0.6 per cent. solution of sodium chlorid. It can be moulded into any desired shape. The interior of the tube is partially filled with a saturated solution of sulphate of zinc in which is immersed the strip of amalgamated zinc. To the upper end of the zinc the conducting wire is attached.

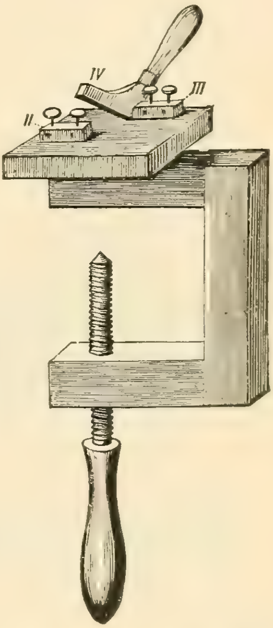

Fig. 367.—Du Bois-Reymond Friction Key.

The v. Fleischl brush electrode is similar to the preceding except that the end of the tube is closed by the brush of a camel's-hair pencil.

The d'Arsonval electrode consists of a glass tube containing a silver rod coated with fused silver chlorid. The interior of the tube is filled with normal salt solution 0.6 per cent. and the end closed with a thread or plug of asbestos which is made to project beyond the tube for a short distance.

Any one of these three electrodes is suitable for physiologic experimentation, as their free ends neither corrode the tissues nor develop electric currents.

Keys.—Muscle and nerve-tissues are conductors of electricity. When, therefore, the terminals (the non-polarizable electrodes) of the wires of a cell are placed in contact with either a muscle or a nerve a circuit is *made* through which a current of electricity flows; when one or both are removed, the circuit is *broken* and the current ceases. In practical work it is often necessary to keep the electrodes in contact with the tissues for a variable length of time. The circuit, however, may be alternately *made* and *broken* at will by interposing along the return wire a mechanic contrivance known as a key, of which there are many forms.

The du Bois-Reymond Friction Key.—This consists of a plate of vulcanite attached to a screw clamp by which it can be fastened to the edge of a table (Fig. 367). The surface of the vulcanite plate carries two rectangular blocks of brass, each of which has two holes drilled through it, for the insertion of wires, which are held in position by small screws. A movable bridge of brass, provided with an ebonite handle, serves to make connection between the blocks. There are two ways of interposing this key in the circuit.

1. *As a Simple Key.*—For this purpose one of the wires, usually the negative, is carried from the cell to one block and then continued from the second block. When the bridge is down, the circuit is made and the current passes; when it is up, the circuit is broken.
2. *As a Short-circuiting Key.*—When used for this purpose, the wires of the cell are carried to the inner holes of each block and then continued from the outer holes to the tissues or to some form of apparatus which it is desired to actuate. When the key is closed *i. e.*, when the bridge is down, the current on reaching the key, will divide, one portion passing across the bridge and so back to the cell, the other portion passing to the tissue or apparatus. The amount of the current which is returned to the cell through the short circuit will be proportional to the resistance of the longer circuit. As the latter is usually great in comparison with the former; practically all the current is short-circuited. When the bridge is lowered, therefore, the current is short-circuited; when it is raised, the current flows into the longer circuit through the tissue or apparatus.

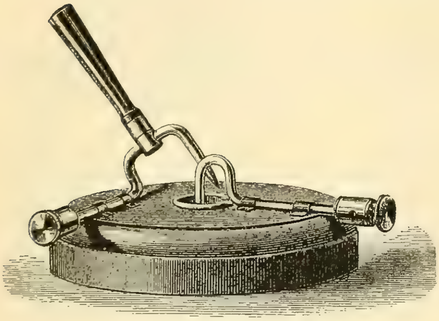

FIG. 368.—A MERCURY KEY.

The Mercury Key.—In this form the connection is established by means of mercury. It consists of a circular block in the center of which there is a cup containing mercury (Fig. 368). At opposite points there are binding posts, one of which is provided with a rigid fixed copper rod passing into the mercury; the other is provided with a movable bent rod which may be made to dip into or be withdrawn from the mercury by the ebonite handle.

The effect of a constant or galvanic current on a muscle or nerve will depend to some extent on its strength. This may be accurately regulated by means of an apparatus known as—

The **Rheocord.** With this apparatus an electric current may be divided, one portion continuing through a conductor back to the battery, the other portion being sent off through the nerve. The strengths of these two currents are inversely proportional to the resistances of their circuits. A simple form of rheocord (Fig. 369) consists of a long wire arranged for convenience in parallel lines on a small wooden base and connected at its two ends with binding posts

A and B. The resistance of this wire, 1.6 ohms, can be increased by the introduction of small resistance coils, between D and B, varying from 5 to 20 ohms.

The two binding posts A and B are connected with the positive and negative poles of an electric cell respectively. A simple key is placed in the circuit.

From A, a wire passes to one of the electrodes on which the muscle or nerve rests. A second wire passes from the second electrode to a clamp S, by way of the binding post C, which can be fastened to the long wire at any given point. The current, on reaching A, will divide into two branches, one of which will pass along the wire A, B, and thence back to the cell; the other will pass through the nerve and back to S and thence also to the cell. The amount of current passing through the nerve circuit will be inversely proportional to the resistance of the nerve and directly proportional to the difference of potential between A and S. If S is close to A, the difference of potential is slight. If S is removed from A toward B, the difference of potential is increased and the current sent through the nerve circuit is increased.

In many experiments it is necessary to *reverse* the direction of the current, in other experiments to *deflect* it, without changing the position of the electrodes. Both these results may be accomplished by the use of—

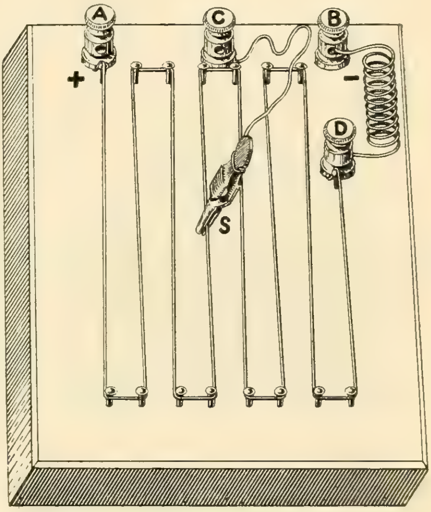

FIG. 369.—RHEOCORD.

Pohl's commutator. This is a round block of wood with six cups, each of which is in connection with a binding post (Fig. 370). In each of the two cups marked 1 and 2, + and —, is inserted one end of a copper wire bent at right angles. The other ends of the wires are supported and insulated by a hard-rubber handle. To the top of each wire is soldered a semicircular copper wire. This arrangement permits of a rocking movement, whereby the opposite ends of the semicircular wires can be made to dip into cups 3 and 4, and into cups 5 and 6 alternately. Two wires crossed in the middle of the block serve to connect opposite pairs of cups. When in use, the cups are filled with clean mercury. The method of using the commutator is as follows:

1. *As a Current Reverser.*—The positive and negative poles of the

electric cell are connected by wires with binding posts 1 and 2 respectively. A key is interposed in the circuit. Wires are then carried from binding posts 3 and 4 to the electrodes in connection with the muscle or nerve. The rocker of the commutator is so turned that the ends of the semicircular wires dip into cups 3 and 4. The direction of the current will be on the closure of the circuit from 1 to 3, then from 3 along a wire to and through the tissue and back to 4, and thence to the cell. If the position of the rocker be now reversed so that the opposite ends of the semicircular wires dip into cups 5 and 6, the direction of the current through the tissue will be reversed. The positive current, after entering binding post 1, will flow to 5; then along one of the cross wires to 4; then along a wire to and through the tissue and back to 3, along the opposite cross wire to 6, thence to 2 and so back to the cell.

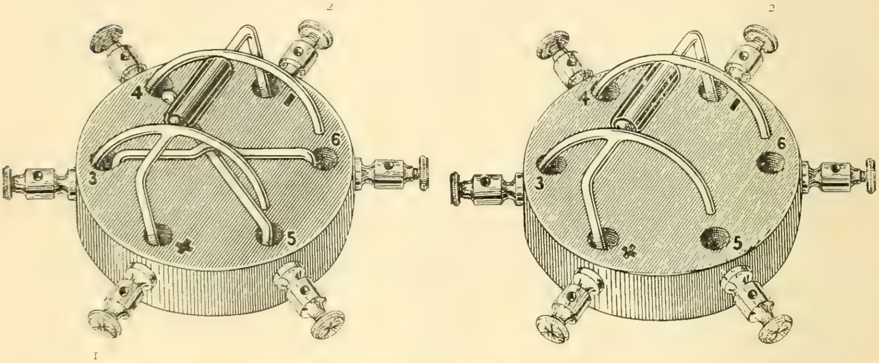

FIG. 370.—POHL'S COMMUTATOR. A. Arranged as a current reverser; B, as a current deflector.

2. *As a Current Deflector.*—When it is desirable to deflect the current to two pairs of electrodes differently situated, wires are carried from binding posts 3 and 4 to one pair, and from 5 and 6 to the other pair. The cross wires are then removed. According to the position of the rocker the current will be deflected to one or the other.

The Inductorium.—This is an apparatus designed for the purpose of obtaining single or rapidly succeeding electric currents by induction. Its construction is based on facts discovered by Faraday, some of which are the following:

If two circuits, a *primary* and a *secondary*, are placed parallel to each other, the former connected with a galvanic cell, the latter with a galvanometer, it is found that, at the moment the primary circuit is made, and at the moment it is broken, a current is *induced* in the secondary circuit, as shown by a momentary deflection of the galvanometer needle. During the continuous flow of the current through the primary circuit there is no evidence of a current in the secondary circuit. The induced current is but of momentary duration. The current flowing through the primary circuit is termed the *inducing*, the current flowing through the secondary circuit the *induced* current.

The induced current is *opposite* in direction to that of the inducing current when the circuit is made or closed; it is in the *same* direction, however, when the circuit is broken or opened.

If the circuits are arranged in the form of coils, it is found that, other things being equal, the strength of the induced currents will be proportional to the number of turns in the coils.

If the coils are placed at varying distances from each other, the strength of the induced current varies, *increasing* as the coils are approximated, *decreasing* as they are separated.

Approximation or separation of the coils while the current is flowing through the primary circuit develops an induced current, which disappears, however, the moment the movement of the coil ceases. A sudden increase or decrease in the strength of the inducing current also develops an induced current.

When the coils are approximated or the primary current increased in strength, the induced current is opposite in direction to that of the inducing current; with the reverse conditions, the induced current has the same direction.

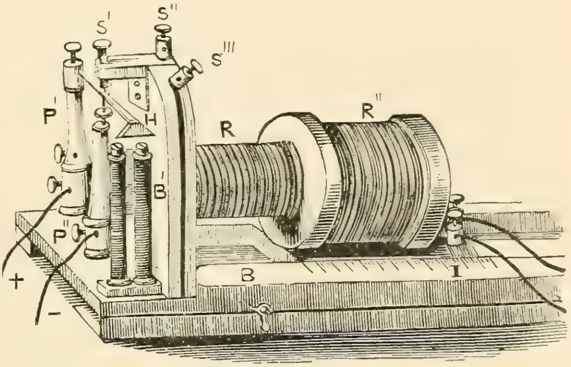

FIG. 371.—INDUCTORIUM OF DU BOIS-REYMOND. R′, Primary, R″, secondary spiral. B. Board on which R″ moves. I. Scale. + —. Wires from battery. P′, P″. Pillars. H. Neef's hammer. B′. Electro-magnet. S′. Binding screw touching the steel spring (H). S″ and S‴. Binding screws to which to attach wires where Neef's hammer is not required.

The *induced currents* have been termed, in honor of their discoverer, Faradic currents.

The **du Bois-Reymond inductorium,** based on the foregoing facts, consists essentially of two coils of insulated copper wire, termed primary and secondary (Fig. 371).

The primary coil, R′, consists of thick copper wire wound around a wooden spool attached to a vertical support. The beginning of this coil is at the binding post S″, its termination either at binding post P″ or S‴. In the course of this primary wire or circuit, there are placed two vertical bars of soft iron, B′, connected at their bases to form a horseshoe magnet, around the ends of which the wire is coiled. The object of this device will be explained later.

Inside the primary coil there is placed a bundle of soft iron wires, which, as soon as the circuit is made, become magnetized, with the effect of increasing the action of the inducing current.

The secondary coil, R″, consists of a much greater number of turns of a finer copper wire, the ratio being about 40 to 1, also wound around a spool, having a tunnel sufficiently large to enable it to slide over the primary. By these means the strength of the induced current is increased. As a result of the construction of the inductorium, the low electro-motive force of the cell is transformed into the high electro-motive force characteristic of the induced current. As the number of turns of wire in the secondary coil is to the number in the primary, so are the electro-motive forces in the secondary coil to those in the primary coil.

The secondary coil slides along a track, B, which permits it to be moved toward or away from the primary. The distance between the two coils can be measured and the strength of the induced current again reproduced, other things being equal, by means of a centimeter-millimeter scale pasted on the edge of B.

The ends of the wire of the secondary coil are fastened to two binding posts to which conducting wires provided with hand electrodes can be attached.

The inductorium may be used for obtaining either a single current or a series of rapidly repeated induced currents.

The Single Induced Current.—On account of its high electro-motive force, its penetrative power, and short duration, the single induced current is a most convenient and suitable form of stimulus for many purposes. In order to obtain such a current, the positive wire of the cell is carried to binding post S″, and the negative wire either to S‴ or P″. A key is placed in the primary circuit. The course of the current will then be on the closure of the circuit from the cell to S″, thence around R′ to S‴, and so back to the cell; or if the negative wire is connected with P″, the course of the current on leaving R′ will be through the coils surrounding the two vertical bars B′, thence to P″, and so back to the cell. If the secondary coil be placed close to the primary and the wires of the secondary brought into contact with a muscle, it will be found that with both the make and the break of the primary circuit a current is induced in the secondary, as shown by a short quick pulsation of the muscle; but during the time of closure of the circuit, the induced current is wanting, as shown by the quiescent condition of the muscle. It will be apparent, however, from the energy of the contraction that the break induced current is a more efficient stimulus than the make induced current. That this is the case is made evident by removing the secondary to the end of the slide-way and then gradually bringing it toward the primary half a centimeter at a time, making and breaking the circuit after each movement until a pulsation of the muscle occurs. It will be found to occur first on the break of the circuit. As the secondary approaches the primary a position will be reached when a pulsation occurs on the make as well as on the break of the circuit, though it will be less pronounced.

The explanation offered for this difference in the strength of the two induced currents is as follows: With the make of the circuit and the passage of the battery current through the primary coil there is induced in the neighboring and parallel turns of the wire an *extra* current opposite in direction to the primary current. This extra or self-induced current antagonizes and prevents the current from attaining its maximum development as quickly as it otherwise would, and therefore its efficiency as an inducer of a current in the secondary is diminished. On the break of the circuit the primary current disappears quickly, and as there is nothing to retard its disappearance its efficiency as an inducer of a current in the secondary coil is not diminished. It is not infrequently stated that the disappearance of the primary current induces in the neighboring coils a *break extra current* corresponding in direction which assists in the development of the induced current. This is not the case, however, as no break extra current is developed in the inductorium as ordinarily used when actuated by a battery current of moderate strength.

As it is not so much the intensity of the current as it is rapid variations in intensity that produce effects, it is readily apparent why the induced current developed at the break of the primary is more effective as a stimulus than the induced current developed at the make of the primary circuit. The quantity of the electricity is, however, the same in both cases.

If the secondary be pushed further along the slideway until it largely covers the primary coil, a position will be reached when the make induced current equals in its efficiency as a stimulus the break induced current; and if the secondary be yet further advanced, a position is reached when the make induced current becomes more powerful and efficient than the break induced current, as shown by the greater contraction of the muscle. This result is explained by the fact that the make extra current is now able of itself to induce a current in the secondary coil, on account of its proximity, which, added to that induced by the battery current, produces a current, greater than that induced on the break of the circuit.*

Rapidly Repeated Induced Currents.—As the single induced current is of extremely short duration, it is inefficient as a stimulus in the conduct of many experiments. It is necessary, therefore, to develop it with a frequency that is sufficient to give rise to a summation of effects. The duration of the stimulation may be thus considerably prolonged. This is accomplished by introducing in the primary circuit close to the primary coil an automatic interrupter, usually Neef's modification of Wagner's hammer (Fig. 371). This consists of a vertical post, P′, to the top of which is fastened a metallic spring carrying at its opposite end a steel or iron hammer, H, which hangs over, but does not touch, the two vertical bars of soft iron around which the wire of the primary coil is wound. About the middle of the spring on its upper surface there is a small plate of platinum which is in contact with an adjustable, platinum-tipped screw, S′, carried by a plate of brass in connection with binding post S″.

For the purpose of interrupting the primary circuit frequently in a unit of time, and thus developing induced currents in quick succession, the apparatus is arranged in the following way: The positive and negative poles of the electric cell are connected by wires with binding posts P′ and P″, a key being interposed in the circuit. If the screw S′ is in contact with the spring, the current on the closure of the circuit will enter P′, pass along the spring to S′, thence into and through the primary coil R′, to the coils surrounding the vertical bars B′, then to P″, and so back to the cell.

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* "On certain peculiarities of the inductorium," Prof. Colin C. Stewart, "Univ. Pa. Medical Bulletin," Feb., 1904.

As the current passes around the vertical bars, they are magnetized. The magnetization draws down the hammer, and, in so doing, breaks the circuit at the tip of the screw, S′. The vertical bars are at once demagnetized, and the hammer is restored to its original position by the elasticity of the spring. The circuit is thus re-established, the current flows through the coils, the bars are again magnetized, the hammer is drawn down, to be followed by a second break of the circuit.

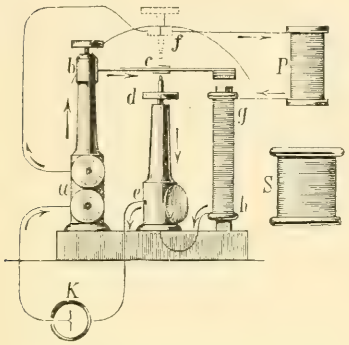

Fig. 372.—Helmholtz's Modification of Neef's Hammer. As long as *c* is not in contact with *d*, *g h* remains magnetic; thus *c* is attracted to *d* and a secondary circuit, *a*, *b*, *c*, *d*, *e*, is formed; *c* then springs back again, and thus the process goes on. A new wire is introduced to connect *a* with *f*. K. Battery.

The number of times the circuit is thus *made* and *broken* per second will vary with the length of the spring.

As each interruption of the primary circuit develops an induced current, it follows that the latter must succeed each other with a frequency corresponding with the frequency of the former. If while the primary circuit is thus being interrupted the wires of the secondary coil be placed in contact with a muscle, the induced current will give rise to contractions which will succeed each other so rapidly that they fuse together, producing a spasm or *tetanus* of the muscle. For this reason these currents are frequently spoken of as *tetanizing* currents, and the procedure as *tetanization* or *Faradization*. These currents also increase in strength as the secondary approaches the primary.

Helmholtz's Modification of the Inductorium.—With a view of equalizing the strengths of the induced currents, Helmholtz suggested a device the adoption of which accomplishes this to a certain extent. It consists (Fig. 372) in connecting with a wire binding posts P′ and S″, and in providing binding post P″ with an adjustable screw which can be raised until the spring comes in contact with it, when the hammer is drawn down by the electromagnet B′. This latter arrangement is practically a short-circuiting key by which a portion of the current is returned to the cell without ever entering the primary coil. The same arrangement, though differently lettered, is shown in Fig. 371. By the use of the entire device the changes in the primary coil are made not by making and breaking the primary current, but by alternately long- and short-circuiting the current. "When the short-circuiting key is opened, the full volume of the primary current flows through the primary coil. When the short-circuiting key is closed, most of the current fails to enter the coil, taking the easier path through the key. Some of the current, however, always flows through the coil and is never diverted. The cycle of changes in the electric condition of the primary coil is thus altered for two reasons:

"First, we no longer have an alternation between a full primary current and none at al —rather an alternation between a full primary current and a weaker one. The difference in the phases is thus lessened, the extent of the change on making and breaking is lessened, and correspondingly the efficiency of the make and break currents induced in the secondary coil is slightly decreased.

"Second, on making the primary current, as in the ordinary coil, the sudden appearance of the primary current is antagonized by the opposing make extra current, with the result that the make induced current is still further reduced; while on breaking the current the break extra current can now flow through the primary coil across the short-circuiting key. This current, trailing behind the disappearing primary current in the same direction, produces the same effect as if the primary current itself were to disappear slowly. As a result the disappearance of the primary current loses its former efficiency as an inducer of secondary currents, and the break induction current is reduced to about the efficiency of the make.

"This so-called 'equalizing' of the make and break induced currents is never perfect, if for no other reason, because the make extra current must take the long circuit through the battery, while the break extra current has an easier path through the short-circuiting key, and is thus greater than the make extra current." (C. C. Stewart.)

THE GRAPHIC METHOD.

The term graphic is applied to a method by which curves or tracings are obtained which represent the extent, duration, and time relations of the movements accompanying physiologic processes. If these movements can be translated in one direction, they may be recorded in different ways:

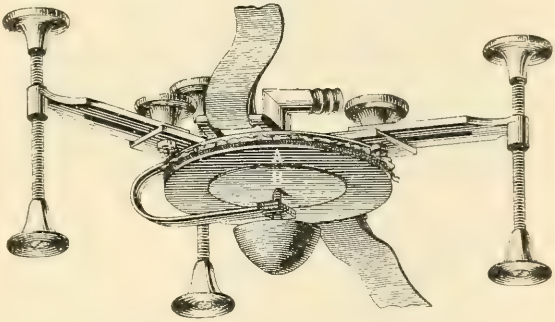

FIG. 373.—A RECEIVING TAMBOUR.

1. By attaching the moving structure—*e. g.*, heart, muscle, etc.—to a delicate lever the free extremity of which is provided with a writing point.
2. By transmitting the movement through a column of air enclosed in a rubber tube the two ends of which are attached to a metallic capsule, covered by a rubber membrane, termed a drum or tambour. When the membrane of the first tambour is pressed or driven inward, the air is forced through the rubber tube into the second tambour and its membrane is pushed outward. As soon as the primary pressure is removed, the membranes return to their former condition. If the membrane of the first tambour is drawn outward, the air in the system is rarefied and the membrane of the second tambour is pressed inward. For the purpose of registering the movement transmitted by the column of air, the second tambour is provided with a light lever supported by a vertical bearing resting on a small metallic disk. The membrane of the first tambour is frequently provided with a button,

which is placed over the moving structure. The inward movement of the membrane of the first tambour produces an outward movement of the membrane of the second tambour, indicated, though magnified, by the rise of the free end of the lever. The reverse movement of the membrane is attended by a fall of the lever. The first tambour is termed the *receiving*, the second the *recording* tambour (Figs. 373, 374).

3. By enclosing an organ—*e. g.*, kidney, spleen, arm, finger, etc.—in a rigid glass or metal vessel which at one point is in communication with a recording apparatus—*e. g.*, (1) a piston provided with a lever (page 483); or (2) a tambour and lever (page 336); or (3) a mercurial manometer carrying a float and pen (page 341). The space between the part investigated and the vessel is filled with fluid. The variations in volume of the organ cause a displacement of the fluid and give rise to a to-and-fro movement which is taken up and reproduced by the recording apparatus.

The writing point may be (1) some form of pen carrying ink which records the movement on a white paper surface, or (2) a piece of metal, glass, or paper which records the movement on smoked paper or glass.

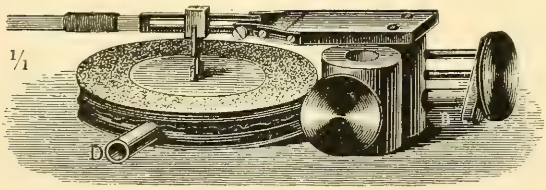

FIG. 374.—A RECORDING TAMBOUR.—(*Marey.*)

The Recording Surface.—The surface which receives and records the movements of a pen or lever is usually that of a cylinder which is covered with glazed paper and coated with a thin layer of soot, obtained by passing the cylinder through the flame of a gas burner. The axis of the cylinder is supported by a metal framework. If the writing point of the lever be placed against the cylinder and a movement be imparted to it, a portion of the soot is rubbed off, leaving a white line behind. If the cylinder be stationary, the rise and fall of the lever are recorded as a vertical line. Such a record shows only the extent of a movement. If the cylinder is traveling, however, at a uniform rate, the rise and fall of the lever are recorded in the form of a curve the width of the two arms of which will depend partly on the rapidity of the movement of the lever and partly on the rate of movement of the cylinder. The cylinder movement is initiated and maintained by clock-work or by the transmission of power by belting to a system of pulleys in connection with its axis. As the tracing is wave-like in form, the cylinder is frequently spoken of as a kymograph or wave recorder (Fig. 375).

From the record thus obtained it is possible to determine not only the extent but also the duration, the form, and the rate of recurrence of any given movement.

The Extent of a Movement.—As the lever not only takes up and reproduces a movement, but at the same time magnifies it, it is essential that the degree of magnification be known, in order to determine the actual extent of the movement. The magnification of the lever is readily determined by dividing the distance between the axis of the lever and its writing point by the distance between the axis and the point of attachment of the structure, and then dividing the height of the tracing by this quotient. The final quotient represents the extent of the movement.

The Time Relations of a Movement.—When recorded in the form of a curve, the duration of the entire movement, or of any one portion of it, can be determined by means of a time marking or chronographic apparatus, consisting of (1) a small signal magnet provided with a movable armature, to which is attached a writing style; (2) an automatic interrupter; and (3) an electric cell.

The Signal Magnet.—The magnet (Fig. 376) is actuated by the electric current made and broken at regular and known intervals by an automatically-acting interrupter placed in the circuit. With each make and break of the circuit the armature and style move alternately downward and upward. The excursion of the style can be readily recorded on a traveling surface. The character and number of the interruptions per second will determine the character of the tracing. If they occur in a rhythmic manner, the tracing will be sinus oidal or wave-like in form. If the time of interruption is of short duration as compared with the time of closure of the circuit, the tracing will be a horizontal line with short vertical elevations at regular intervals.

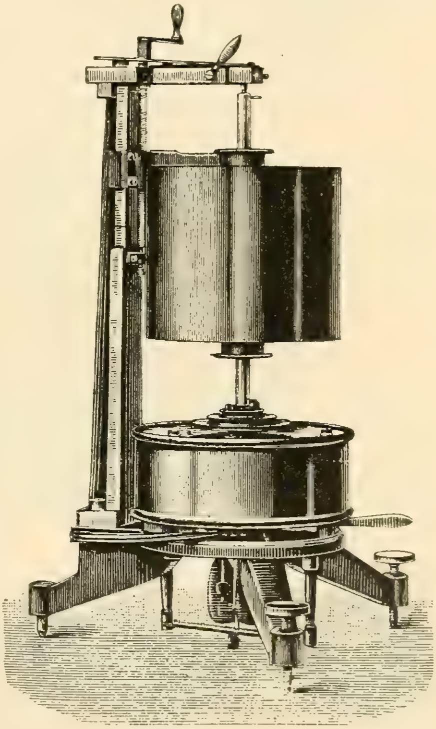

FIG. 375.—KYMOGRAPH. (Boruttau's, Petzold, Leipzig.)

The Automatic Interrupter.—The circuit may be interrupted by vibrating reeds, tuning-forks, metronomes, etc. A well-known form of vibrating reed is shown in Fig. 377. This consists of a metallic frame carrying a coil of wire in the center of which there is a core of soft iron. To the vertical part of the frame there is fastened the reed, the distal end of which is bent to dip into an adjustable mercury cup. When in circuit the current enters the coil, then flows into and through the frame and the reed to the mercury, and thence back to the cell. On the closure of the circuit and the magnetization of the iron core the reed is withdrawn from the mercury, the circuit broken, and the core demagnetized. The elasticity of the spring returns it to the mercury, when the circuit is again restored. The reed may be so constructed that it will be raised and lowered 50, 100, or 200 times a second. The armature of the signal magnet undergoes a corresponding number of elevations and depressions. If the reed vibrates 100 times in a second, the distance from crest to crest of the wave tracing will represent $\frac{1}{100}$ of a second. Interrupters of various kinds have been devised which make and break the circuit from 1 to 250 times a second.

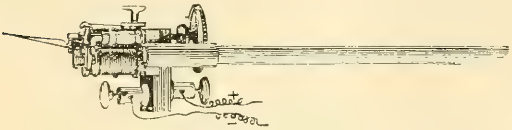

FIG. 376.—SIGNAL MAGNET.

Moist Chamber.—In many experiments, it is necessary to keep the nerve or muscle preparation in a uniformly moist atmosphere. To secure this, a moist chamber is employed (Fig. 378). This consists of a hard-rubber platform, supported by a piece of brass, which slides up and down a vertical rod, and which can be clamped at any height. By means of a short lever the vertical rod can be turned, carrying the platform from side to side. The rod is secured to a firm iron base.

Six double binding posts for the attachment of wires pass through the platform. Near the side of the upper surface of the platform there rises a vertical rod, carrying a clamp for holding the femur of a nerve-muscle preparation, as well as a horizontal rod for supporting three pairs of non-polarizable electrodes. A groove around the outer edge of the platform receives a glass shade, which covers the whole. The air of the chamber is kept moist by placing in it pieces of blotting-paper saturated with water.

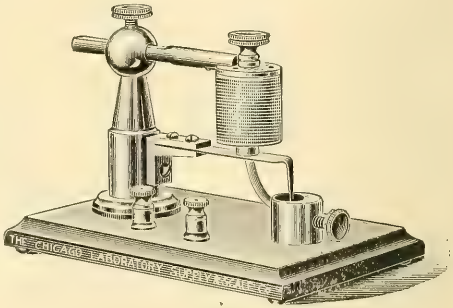

FIG. 377.—PAGE'S VIBRATING REED. (Reichert's modification.)

From the under surface of the platform there descends a rod, which, by means of a double binding screw, supports a horizontal rod, modified at one end to carry the delicate axis of a light stiff recording lever. The end of this lever is pointed, to enable it to write on a smoked glass or paper. Beneath the axis is a strip of brass, carrying a screw, which gives support to the lever until the instant the contraction of the muscle begins. This screw, the after-loading screw, also enables the lever to be placed in a horizontal position. The portion of the lever near the axis is provided with a double hook, the lower portion of which serves for the attachment of the weight by which the muscle is counterpoised.

In some experiments, as in the registration of a muscle contraction under varying conditions, it is necessary to give the lever mass by attaching weights directly beneath the muscle. This, however, introduces certain errors in the movements of the lever, which somewhat deform what would otherwise be the normal curve. If the weight be attached, not opposite to the muscle attachment, but close to the axis of the lever, the undesirable acceleration of the lever movement, during both contraction and relaxation, is largely prevented. The lever may be a straw, a strip of celluloid or aluminium. It should be as light as possible. The writing point may be made of stiff paper, a piece of tinsel, glass or aluminium. It should have sufficient elasticity to keep it in contact with the cylinder during the excursion of the lever. The writing point should be placed as nearly parallel as possible to the surface of the cylinder.

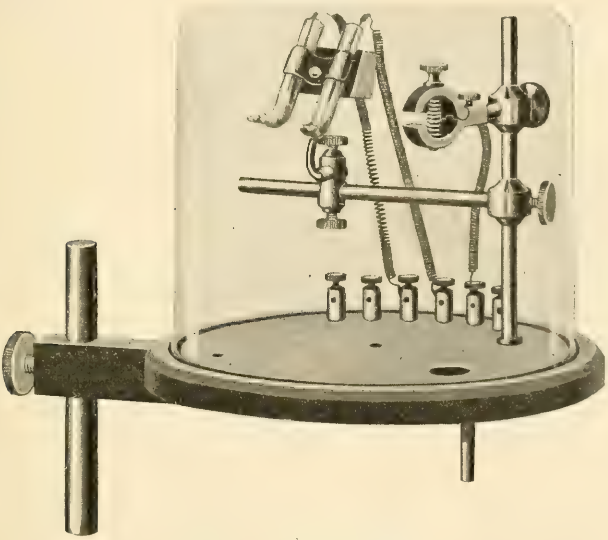

FIG. 378.—MOIST CHAMBER.

Normal Saline Solution.—To prevent drying and a loss of irritability the tissue under investigation should be kept moist with the normal saline solution (NaCl 0.6 per cent.). This solution very largely prevents either absorption or extraction of water from the tissues and thus retards chemic changes in their composition.

Ringer's solution, largely used for the same purpose, is made by saturating 0.65 per cent. NaCl solution with calcium phosphate and then adding 2 c.c. of a 1 per cent. solution of potassium chlorid to each 100 c.c.

The Galvanometer and Capillary Electrometer.—In the detection and investigation of the electric currents of muscles, nerves, and other tissues, the physiologist is limited to the galvanometer and capillary electrometer. The principle of the galvanometer is based on the fact that an electric current flowing through a wire parallel in direction with a magnetic needle will tend to set the needle at right angles to the direction of the current. The essential requisite of any galvanometer used for physiologic purposes is that it will respond quickly to the influence of extremely weak currents. This is realized by the use of small light needles, the adoption of the astatic system, or some similar device by which the directive influence of the earth's magnetism is eliminated, and the multiplication of the number of turns of the wire in the coils which surround the needle.

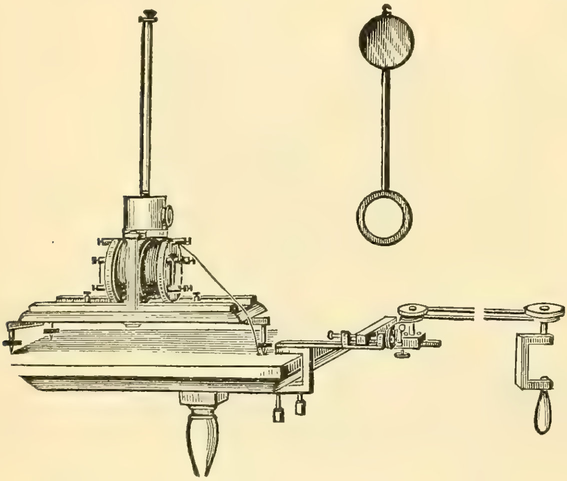

Fig. 379.—Wiedemann's Boussole.

The tangent galvanometer, or *boussole*, as constructed by Wiedemann, is the form most frequently employed in physiologic investigations (Fig. 379). It consists primarily of a thick copper cylinder, through which a tunnel has been bored. Within this tunnel is suspended a magnetized ring, just large enough to swing clear of the sides of the chamber. The object of making the magnet ring-shaped is to increase its strength in proportion to its size, and to get rid of the central inactive part. Connected with and passing upward from the magnetized ring through the copper cylinder is an aluminium rod, surmounted by a circular plane mirror. Above the mirror rises a glass tube, which carries on top, on an ebonite support, a little windlass, capable of being centered by three small screws. On the windlass is wound a single filament of silk, which passes down the tube and is attached to the mirror. The magnet can, by this contrivance, be raised or lowered and centered in the copper chamber. Deflections of the mirror from currents of air are prevented by inclosing it with a brass cover provided with a glass window. The coils are placed on each side of the copper chamber, and supported by a rod, on which they slide. By this arrangement they can be approximated until they meet and completely conceal the cylinder. By varying the position of the coils the influence of the current upon the needle can be increased or diminished. An advantage which this galvanometer possesses is the damping of the oscillation of the needle, so that it quickly comes to rest after deflection. This is accomplished by the development of induction currents in the copper cylinder, the direction of which is opposite to that of the movement of the needle. The instrument, therefore, is aperiodic—that is to say, when the needle is influenced by a current it moves comparatively slowly until the maximum deflection is reached, when it comes to rest without oscillations. When the circuit is broken the needle swings slowly back to zero, and again comes to rest without oscillations.

Inasmuch as the needle is not astatic, it is rendered so by the use of an accessory magnet—the so-called Hauy's bar. This magnet, supported by a rod directed perpendicular to the coils, is placed in the magnetic meridian, horizontal to the needle, with its north pole pointing north. By sliding the magnet toward the needle the directive influence of the earth's magnetism is gradually diminished, and when it is reduced to a minimum the needle acquires its highest degree of instability. By means of a pulley an angular movement can be imparted to the end of the accessory magnet in the direction of the magnetic meridian, which serves to keep the needle on the zero of the scale. The deflections of the needle are observed by means of an astronomic telescope, above which is placed a scale divided into centimeters and millimeters, and distant from the galvanometer about six or eight feet. As the numbers on the scale are reversed, they will be seen in the mirror in their natural position, and with the deflection of the needle the numbers will appear as if drawn across the mirror. The extent of the deflection is readily determined when the needle comes to rest.

The reflecting galvanometer of Sir William Thompson is also used for the same purposes.

The Capillary Electrometer.—Notwithstanding the extreme sensitiveness of the modern galvanometer, it has been found desirable, in the investigation of many physiologic processes, to possess some means which will respond even more promptly to slight variations in electro-motive force. This has been realized in the construction by Lippmann of the capillary electrometer. The principle of this apparatus rests upon the fact that the capillary constant or the surface-tension of mercury undergoes a change upon the passage of an electric current, in consequence of a polarization by hydrogen taking place at its surface. If a capillary glass tube be filled with mercury and its lower end inserted into a solution of sulphuric acid, and the former connected with the positive and the latter with the negative electrode, it will be observed, upon the passage of the current, that a definite movement of the mercury takes place, in the direction of the negative electrode, in consequence of the diminution of its capillary constant or the tension of its surface in contact with the acid. As a reverse movement follows a cessation of the current, a series of oscillations will follow a rapid making and breaking of the current. If the direction of the current is reversed, the capillary constant is increased and the mercury ascends the tube toward the negative pole. From facts such as these Lippmann constructed the capillary electrometer, a convenient modification of which devised by M. v. Frey, is shown in Fig. 380. This consists of a glass tube, *A*, forty millimeters in length, three millimeters in diameter, the lower end of which is drawn out to a fine capillary point. The tube is filled with mercury and its capillary point immersed in a 10 per cent. solution of sulphuric acid. The vessel containing the acid is filled to the extent of several millimeters with mercury also. The mercury in the tube is put in connection with a platinum wire (*a*), and the acid in the vessel with a second wire (*b*). When a constant current passes into the apparatus in the direction from *b* to *a* the mercury is pushed up the tube, and, upon the breaking of the current, it may or may not return to the zero-point. For the purpose of measuring in millimeters of mercury the pressure necessary to compensate this change in the capillary constant produced by the electro-motive force of polarization, the apparatus is provided with a pressure-vessel, *H*, and a manometer, *B*. This electrometer can be applied to any microscope having a reversible stage. The oscillations of the mercury can then be observed with the microscope provided with an ocular micrometer (Fig. 381). The special advantage of the electrometer is, that it will respond instantly to any variation in the electro-motive force, and indicate a

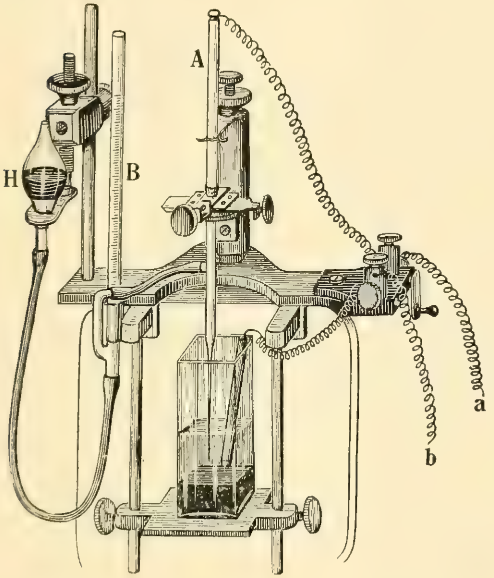

FIG. 380.—VON FREY'S CAPILLARY ELECTROMETER.

difference of potential, according to Lippmann's observation, as slight as the $\frac{1}{10080}$ of a Daniell. These rapid oscillations can be recorded by photographic methods.

In using either the galvanometer or the electrometer for detecting the existence of electric currents or differences of potential in living tissues, it is absolutely essential that non-polarizable electrodes be employed in connection with it.

DISSECTION OF THE HIND-LEG OF THE FROG.

Much of our knowledge of the physiologic properties of muscles and nerves has been derived from the study of the muscles and nerves of the cold-blooded animals, especially of the frog, for the reason that in these animals the tissues retain their vitality under appropriate conditions for a considerable period of time after death or removal from the body. The muscles generally employed for experimental purposes are the gastrocnemius, the sartorius, the semimembranosus, the gracilis, and the hyoglossus. The nerve generally employed is the sciatic. Both muscle and nerve may be studied independently of each other, or they may be studied together, as when in their usual physiologic relation. For this latter purpose the gastrocnemius muscle and sciatic nerve are employed, constituting the so-called "nerve-muscle preparation."

For these, and many other reasons, the student should familiarize himself with the general anatomy of the frog, and especially with the anatomy of the posterior extremities.

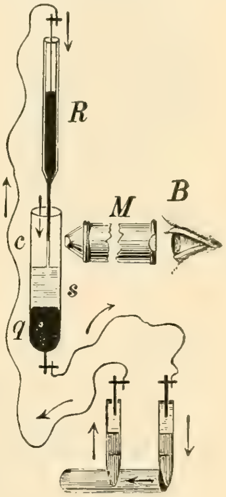

FIG. 381.—CAPILLARY ELECTROMETER. *R.* Mercury in tube; capillary tube. *s.* Sulphuric acid. *q.* Hg. *B.* Observer. *M.* Microscope.

Preparation of the Frog.—Destroy the frog by plunging a pin through the skin and soft tissues covering the space between the occipital bone and the first vertebra until the point is stopped by the vertebra. Turn the pin toward the head and push it into the brain cavity; move it from side to side and destroy the brain. Pass the pin into the spinal canal and destroy the spinal cord. With a stout pair of scissors cut off the body behind the fore-limbs. Remove the viscera and the abdominal walls. Draw the hind-legs out of the skin. Place the legs on a glass plate, back uppermost, and moisten them freely with normal saline solution.

Observe on the outer side of the dorsal surface of the thigh the following muscles (Figs. 382, 383). The triceps femoris (tr), made up of the rectus anticus (ra), the vastus externus (ve), and the vastus internus (vi), not seen from behind; on the inner side, the semimembranosus (sm) and the rectus internus minor or gracilis (ri″). Between these two groups, note the biceps femoris (b). Above the thigh observe the gluteus (gl), the ileococcygeus (ci), and the pyriformis (p).

In the leg observe the gastrocnemius (g) with its tendon (the tendo Achillis), the tibialis anticus (ta), and the peroneus (pe).

Turn the frog on its back and note the muscles on the ventral surface of the thigh, the rectus internus major (ri′), and minor (ri″), the adductor magnus (ad″), the sartorius (s), the adductor longus (ad′), and the vastus internus (vi). In the leg, in addition to those already seen from behind, note the tibialis posticus (tp) and the extensor cruris (ec).

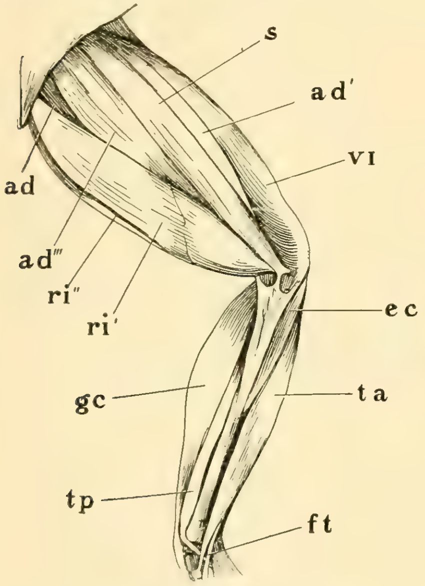

Fig. 382.—Leg Muscles of the Frog. Ventral Surface.—(*Ecker.*)

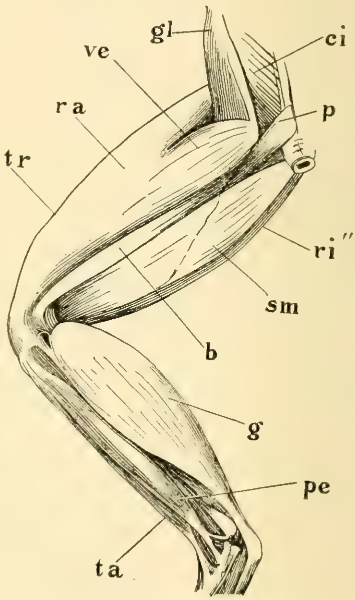

Fig. 383.—Leg Muscles of the Frog. Dorsal Surface.—(*Ecker.*)

Note in the abdominal cavity the three large spinal nerves, the seventh, eighth, and ninth.

Dissection of the Sciatic Nerve.—The sciatic nerve is composed of the seventh, eighth, and ninth spinal nerves. After its emergence from the pelvic cavity, it passes down the thigh between the semimembranosus and the biceps muscles, in company with the femoral blood-vessels. Below the knee it divides into the tibialis and peroneus nerves; the former sending branches into the gastrocnemius. In its course, the sciatic sends branches to the muscles of the entire leg.

Carefully separate the biceps and semimembranosus by tearing the connective tissue uniting them. The sciatic nerve and femoral blood-vessels come into view; with a bent glass rod gently separate the nerve from its surroundings from the knee to the thigh. Begin at the knee. In order to expose the nerve at the pelvis, it will be necessary to divide the pyriformis and the ileo-coccygeus muscles. Care must here be exercised, so as not to injure the nerve which lies immediately beneath. Lift up the uro-style with the forceps and separate it from the last vertebra. With the scissors cut off the vertebral column above the seventh vertebra. Place the legs on the dorsal surface and then divide the seventh, eighth, and ninth vertebræ lengthwise. With the forceps lift up one lateral half of the vertebræ and free the nerve as far as the knee by dividing connective tissue and nerve branches. Be careful not to injure the nerve with scissors or forceps.

The Nerve-Muscle Preparation.—Divide the tendo Achillis just below its fibro-cartilaginous thickening at the heel, and detach the gastrocnemius up to the knee. Cut through the tibio-fibular bone just below the knee-joint. Cut the femur transversely near its middle and remove the muscles from the lower end, carefully avoiding injury to the nerve. The completed preparation consists of the gastrocnemius muscle, the sciatic nerve, with half of the seventh, eighth, and ninth vertebræ and the lower half of the femur.

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